NAVAL POSTGRADUATE SCHOOL

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THESIS

A SIMULATOR EVALUATION OF
PILOT RESPONSE TO LOW FREQUENCY
AIRCRAFT VIBRATION WITH AUDIO FEEDBACK

by

Michael Wayne Mentas

March 1982

Thesis Advisor: D. M. Layton

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significant reversal of the adverse vibration stress duration function above expected values. Detailed conclusions and recommendations are presented.

A Simulator Evaluation of Pilot Response to Low-Frequency Aircraft Vibration with Audio Feedback

by

Michael Wayne Mentas
Lieutenant, United States Navy
B.S., University of Idaho, 1975

Submitted in partial fulfillment of the
requirements for the degree of

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I. INTRODUCTION

Aircraft flying through a turbulent medium are subjected to induced vibrations. The turbulence can be due to (1) weather phenomena, (2) differential heating near the ground, (3) air movement and (4) various natural obstructions to air movement, e.g., hill features. The vibrations are maximum closer to the ground and they are more frequent at higher speeds. Modern attack aircraft have to fly at low altitudes, often below 150 feet to avoid radar detection, with speeds around 0.9 Mach to have the advantage of surprise. Most of these aircraft fly for reasonably long periods, around 90-100 minutes, exposed to turbulent induced vibrations as well as inherent airframe oscillations.

Additional sources of airframe vibrations are (1) engine vibrations which are structure borne and reach the pilot as well as the instrument displays and controls and (2) armament vibrations which depend on the type of armament used, rate of firing and the impact transmitted from gunbase to aircraft structure. Hunting in automatic flight control systems can add to the problem of vibrations experienced by the pilot.

Aircraft vibrations are conveyed directly to crew members through seat cushions, rigid arms rests and headrests in contact with body parts. Secondary paths include the control column, navigator's desk, sighting devices and even stiff breathing lines. The pilot or crewmember is often referred to as being in a state of mechanical whole body vibration.

The effects of mechanical whole body vibration have been well documented. A survey of the international literature [Ref. 1] shows that

impairment of visual, motor and sensory motor processes occurs, for mainly biomechanical reasons, during and in consequence of the effect of mechanical whole body vibration. Numerous tracking investigations, tests of visual performance especially visual acuity, and delicate motor activity confirm these observations. Most of these studies also represent a quantitative relationship between the degree of impairment of performance and the physically defined vibration stress. In addition, there are isolated references to effects on performance due to vibration which cannot be explained completely by biomechanical effects. These appear to include activities in situations of vigilance requiring a high degree of alertness [Ref. 2].

Recent technological advances in the aerospace industry have resulted in higher-performance fighter aircraft, requiring extremely high levels of motor sensor activity and sustained alertness in the normal operation of sophisticated flight control and weapon systems. Current design vibration protection aims are to (1) prevent injury, (2) enhance ability to perform, (3) increase comfort, and (4) reduce fatigue. The application of these objectives to modern aircraft has been limited to the reduction of the biomechanical effects of whole body vibration, e.g., soft, thick seat cushions, restraining harness and binders, increased airframe flexibility, and fly by wire control systems. None of these methods, however, are aimed at enhancing the degradation of performance due to increased vibrational stress in situations of high alertness. If anything, the comfort factor aggravates the vibration/alertness couple.

Crede [Ref. 3] defines vibrations as a series of reversals of velocity, whereas Guignard [Ref. 4], defines it as a sustained structure-borne disturbance, applying a translatory movement to the body and perceived by the senses other than hearing. This second definition suggests a possible solution to the performance related vibration/alertness couple anomaly. The sense of hearing has long been a method of cuing alertness in communications systems, radar warning and IFF Systems, radar altimeters and the like. Using this method to aurally cue the degradation of performance due to vibrational stress should decrease the effects of vibration while enhancing performance due to increased alertness.

It becomes apparent then, that further experimental investigation is needed on such unspecific effects of mechanical whole body vibration referred to as the vibration/alertness couple and the validity of vibrational stress effects reduction by aural cuing.

The objectives of this research were:

1. Investigate the problem and ascertain the requirements and factors influencing the design and testing of an aurally enhanced tracking system.
2. Construct a facility for the human factors testing. This facility to include a tracking task simulation, vibrational mode interface, control capability of the testing, and data acquisition of pilot response to vibrational stress and aural enhancement techniques.
3. Conduct testing as realistically as possible in the laboratory, measuring and recording pilot performance and response to vibrational stress and aural enhancement techniques.

4. Analyze the acquired data to determine the degree of performance degradation due to the vibration/alertness couple and the effectiveness of aural cuing. Analysis should account for the learning effects and the various backgrounds of test subjects.

II. SIMULATOR FACILITY

In order to accomplish the previously outlined human factors research objectives, it was necessary to measure the responses of test subjects to vibrational stimuli in a realistic environment. This dictated that testing be accomplished in an aircraft flight simulator that would permit the test subject to simulate, in real-time, manuvering the aircraft within a theoretical low-level flight envelope while engaged in a high-stress tracking task as is required in Air Combat Manuvering (ACM). Along with the flight simulator, facilities were needed that were capable of providing: (1) a dynamic tracking task approximating ACM, (2) a visual display for test subject viewing of the tracking task, (3) induced mechanical whole-body vibration at controllable frequencies and G-levels, (4) outputs of longitudinal and lateral stick position, and (5) a measuring/recording/scoring system for data acquisition.

A. CONSTRUCTION OF THE FLIGHT SIMULATOR

An F-4 Cockpit Procedures Trainer (CPT), Device 2C30, located in H024 Halligan Hall, was utilized as the facility testbed. The facility consisted of the controller's console and cockpit as shown in Figure 1. The trainer was previously used in a cockpit spin indicator system evaluation and was basically configured with the desired outputs of longitudinal and lateral control stick. The control stick output signals consisted of negative and positive D.C. voltage positioning information that was compatible with the Pace TR-10 Analog Computer.

The cockpit glare-shield and radar PPI were removed to accommodate incorporation of the Dynamic Response Scope (DRS) as shown in Figures 2 and 3. The DRS was a Textronix Model T922, Dual Trace Oscilloscope operated in the D.C., X-Y mode. The input to the DRS was supplied by the Analog Computer Summing Circuits via the Signal Control Box, and provided the test subject with visual indication of ACM tracking performance.

A set of Telex Model 1210, headphones was installed in the cockpit for testtape briefing and aural cuing. The audio signals were supplied by the Aural Tracking Monitor Control Amplifier, A Bogen Model MX 60A, which was located external to the cockpit, as shown in Figure 4.

A cloth enclosure was rigged over the cockpit to deprive the test subject of external references during testing.

B. CONSTRUCTION OF SHAKER SYSTEM AND COCKPIT INTERFACE

Whole body vibration was produced by mechanically interfacing a Calidyne Shaker Table and an LTV Servo Control System Model 219, to the aft of the cockpit module. The shaker table was fastened to the concrete floor with 1/2 inch, expandable-sleeve impact bolts. The interface to the cockpit was designed and constructed so as to transmit maximum vibrational energy to the cockpit frame. The stress-box was constructed of 6 inch channel-iron with 2 inch angle-iron brace and extension. The 6 foot extensions were bolted to the cockpit module base and provided a uniform structural load across the stress-box. The shaker table was bolted to the stress-box using two drilled 1/4 inch steel plates, sandwiching a 1 inch hard-rubber damper section. The interface is shown in Figure 5.

Once the Shaker System was connected, a Statham accelerometer with associated equipment was mounted to the stress-box for G-level calibration and monitoring by the shaker control section, as shown in Figure 6.

C. CONSTRUCTION OF THE MONITOR AND CONTROL FACILITY

The control and monitor facility was constructed around the flight simulator. Figure 7, is an overall view of the facility. Shown is the flight simulator control console that was used to control both the cockpit and simulator functions. Also shown is the various equipment used in the testing. A list of the equipment used to construct the facility is contained in Appendix A. The components requiring adjustment and monitoring were placed at the control section, and the other components were placed as required for the testing procedure. The control section is shown in Figure 8. Equipment at the control section consisted of the tape deck, analog computer, signal monitor digital voltmeter, and the signal control box. The heart of the control system was the analog computer, as shown in Figure 9.

One track of the four-track tape deck was dedicated to aural briefing during the test procedure. The output of the aural track of the tape deck was routed to the Aural Tracking Monitor Control Amplifier where it was mixed with the aural tracking tone and fed to the headphones in the cockpit. Two other tracks of the recorder were used in the tracking task, and will be described later.

The outputs of the flight simulator were routed to the signal control box using coaxial cables, and to the 8-track recorder, as shown in Figure 10. The longitudinal and lateral stick outputs were the inputs

to the analog computer Longitudinal/Roll circuits, shown in Figure 11, that were used to amplify the signals and simulate aircraft dynamic response. The longitudinal circuit approximates the Short Period motion of a high performance, fighter type aircraft at 0.9 Mach. The output used was selectable as angle of attack, α, or pitch angle, θ. For testing purposes, the angle of attack was used rather than pitch angle due to the lack of airspeed/altitude input to compensate pitch angle. The angle of attack, however, varied as a function of the analog computation of δ_e, very closely approximating the dynamics of pitch rate at high α. The lateral circuit is an approximation of roll response, ϕ, from lateral inputs to a stable aircraft. A step input to this circuit caused a return to the null position after the input was removed. These two outputs, α or θ and ϕ, were used as inputs to the summing circuits, as shown in Figure 12.

The two tracks of the tape deck used in the tracking task contained pre-recorded, two-axis signal information approximating the target movement. An analog reproduction of these signals is shown in Figure 13. The two signals from the tape deck were fed by coaxial cables to the 8-Track Recorder and the analog computer summing circuits via the signal control box as shown in Figures 10 and 12.

The summing circuits compared the taped signals and the outputs from the flight simulator and the difference signals were output to the test subject Dynamic Response Scope. The test subject was then able to vary the controls in order to "zero" the displayed signal in pitch and roll.

The X and Y axis outputs from the summing circuits were also fed to the Remote Dynamic Response Scope for monitor viewing, and to the analog computer scoring circuits.

In order to measure the effectiveness of the subject's response, a scoring circuit was constructed in the analog computer. The difference signals from the summing circuit, representing positive and negative error signals in longitudinal and lateral directions, were fed to amplifiers and detected, as shown in Figure 14. The detected outputs were fed to the comparator IN-1 terminal. An input bias voltage was patched to the IN-2 terminal which provided a variable score-threshold and effectively sized the Dynamic Response Scope display scoring area. When the comparator relay triggered, the output of the Aural Tracking Tone Generator, a WAVETEC Model 145, Variable Controlled Generator (VCG) was fed to 8-track recorder for scoring indication and switched to the Aural Tracking Monitor Control which fed the cockpit headset. The VCG provided a variable frequency audio tone, increasing in pitch relative to outside target area distance, to the test subject for audio reinforcement of the visual indication. When the comparator was below score-threshold, the VCG output was used to trigger a Frequency Counter, a Monsanto Model 100A, which provided a cumulative score of on-target time.

D. PREPARATION AND RECORDING OF TEST PROCEDURES TAPE

The tape used in the test procedure contained three trial tracking tasks and a test sequence, all separated by rest periods. The sequence of events on the test procedure tape recording are contained in Table I, as defined by counter-reading and time intervals.

In order to generate the two-dimensional target tracking task for recording, a test tape control circuit was constructed as shown schematically in Figure 15. Two center-top potentiometers were used to vary a D.C. output to the summing circuits in the analog computer, and to the record inputs of the Alpha Model 434, Tape Deck. With the cockpit longitudinal and lateral control stick inputs zeroed, the target control unit potentiometers were adjusted for desired target diversion on the Remote Dynamic Response Scope (RDRS), a Hewlett Packard Model 1300A, X-Y Display.

The trial tasks recorded on the tape consisted of (1) a vertical trial tracking task, (2) a horizontal trial tracking task, and (3) a two-axis trial tracking task. The trial tasks were separated with appropriate rest periods and an oral briefing on procedures. A transcript of the briefing is contained in Appendix B. Following the trial tasks, a two-axis test sequence was recorded of approximately 45 minutes in duration, in which random target excursions from center position on the RDRS were made in 1 cm/sec deflection rates.

III. APPROACH TO PROBLEM

To test the possible influence of whole-body vibration on alertness and to evaluate the aural enhancement technique, an experimental procedure was developed utilizing the simulator facility. Volunteer test subjects were exposed to a test series which was organized according to pretest exposure training, frequency of vibration and acceleration, and the duration of stress exposure.

A. TEST SUBJECTS

The test subjects participating in this evaluation were volunteer military officers and civilians attached to the Naval Postgraduate School. Nine (9) subjects were used with varying flight experiences and platform proficiencies. A summary of test subject background information is contained in Table II. Five (5) of the subjects were designated pilots and three (3) subjects were designated Naval Flight Officers. The remaining test subject had no previous flight experience. Aviator experience levels ranged from 400 to over 7000 total flight hours. Flight platforms consisted of two (2) helicopters, three (3) light trainer A/C, two (2) jet fighter A/C, and one (1) long-range patrol A/C.

All subjects were healthy and expressed an interest in vibrational-exposure testing.

B. TESTING PROCEDURES

Before each test series, the simulator facility equipment was energized and calibrated. This procedure took approximately one hour to complete. The set-up and alignment procedures are listed in Appendix C.

An oral briefing was given to each individual participant prior to testing, explaining the general purpose of the test and basic equipment operation. Each individual completed the first part of the Simulator Response Project Interview Questionnaire, a copy of which is shown in Appendix D.

Upon completion of the briefing, the test subject entered the cockpit and donned the headphones. The black canvas canopy was secured to exclude outside lighting and noise from the cockpit environment. The eight-track recording system was started and the test sequence commenced as outlined in Appendix E.

In order to achieve a stable performance level before the start of the vibration exposure runs and to normalize the test subjects according to their performance, the subject took part in a series of three DRS tracking familiarization tasks, followed by Phase I, a five minute training period without vibration. This training period response was scored and established a performance baseline for learning-dependent improvement and audio enhancement comparison.

Phase II consisted of another five minute tracking task without vibration but with audio cuing fed to the headphones for off-target indication. The frequency of off-target audio enhancement varied from 100 Hz. at the scoring threshold to 2000 Hz. for off-scope indication. Lack of an audio tone was indication of on-target tracking.

Phase III consisted of ten minutes of tracking while exposed to various predetermined vibrational frequencies and G-levels. The frequency of vibration was stepped at one minute exposure periods from 5 to 50 Hz. in

5 Hz. increments. The G-level magnitude was limited by the power input of the shaker system and therefore varied with the frequency applied to the cockpit interface. The power input, however, was kept constant at 0.4 amperes as indicated on the PA-1 Power Level Meter, for each frequency step. The corresponding G-levels, as indicated in Appendix E, were consistent for each test subject.

Phase IV was a repeat of the ten minute vibrational tracking sequence of Phase III with audio cuing feedback to the headphones for performance enhancement. The G-level magnitudes were kept the same as the previous phase by PA-1 monitoring.

The final sequence, Phase V, consisted of a five minute exposure to a non-vibrational environment without aural cuing. This period was scored to establish a posttest performance baseline for learning-dependent improvement analysis.

All testing was accomplished using the procedures as described. Due to the limited number of test subjects available, all testing was performed in the same sequence for data comparison purposes.

The entire test was approximately one hour in duration. The only rest periods occurred between the familiarization tasks and prior to the commencement of Phase I. Once visual tracking began in Phase I, the subject was required to maintain alert to target movement and stick correction through the end of Phase V.

Subjective comments were solicited at the completion of the test sequence with answers to specific questions on the Project Interview Questionnaire as shown in Appendix D.

C. RECORDING OF DATA

The eight-track analog strip chart recording system acquired all the data for each test run. Figure 16 is a sample of recorded data for a typical test run. The scoring channel indicates duration of on-target time signified by center-channel recording. Off target indication is represented by off-center pen deflection with the magnitude of deflection relative to degree of error. This two dimensional time/magnitude error signal provided pilot over-correction indications, as well as incorrect response indications.

Channels 3 and 4 are analog representations of the two-axis ACM target. Channels 5 and 6 represent the analog response of the pilot to the ACM signal displayed on the DRS. Pilot response to the ACM target signal yields the scoring signal.

IV. TEST RESULTS

Each of the nine (9) test-subjects was exposed to the same test procedures as previously outlined, with an eight-track analog strip chart recording made for each run. Each strip chart was annotated according to test-phase with thirty-eight (38) specific data points established as identified on the Data Analysis Form, a sample of which is contained in Appendix F.

A. PRESENTATION OF DATA

For each scoring increment, the numerical value achieved in seconds, was the total time that the subject was able to keep the pip within the scoring area. In Phase I through Phase V, the score attainable for a particular increment was based upon a 60 second maximum with a less than 60 score reflecting relative success at acquisition and tracking for that time increment. The raw scores for these phases are shown in Appendixes G and H.

The Familiarization Phase was used as an indication of sufficient equipment orientation and to shallow the exponential rise in tracking success due solely to learning-dependent exposure training. The scores, therefore, are not reported. It is pointed out, however, that the least successful score attained during the Two-axis Trial Tracking Task was 51/155 or 33% by subject #2. Also, it is noted that test-subject #9 scores are not shown due to equipment malfunctions that resulted in an abort of the test run. Phase I through Phase V test subject averages and raw scores are presented in graphical format in Figure 17 through Figure 39.

B. DISCUSSION

The average scores for all test subjects versus time, obtained during Phases I, II, and V Training Mode Response without vibration, are shown in Figure 17. It is of particular interest to note the degradation in performance during each phase after approximately two minutes of tracking time exposure. This trend suggests a time-related performance decline as a function of stress duration. Also of interest, is the overall improvement in performance between the different phase periods. This trend establishes a learning-dependent improvement in performance function over the training period. It must be remembered, however, that Phase II Prerun with VCG immediately followed Phase I Prerun without a rest period and that Phase V Postrun did not occur until twenty minutes after the conclusion of Phase II. The significant increase in performance during Phase II with VCG is contrary to the stress duration function and in excess of the learning dependent function which is expected to be exponential in nature. The relative performance improvement during that phase then, can be attributed to a positive increase in alertness due to the audio enhancement.

Figures 18 through 25 show the individual Training Mode Response without vibration graphs. All the subjects reflect the same general trends as previously stated except subjects #1, #5, and #7. Subjects #1 and #5, shown in Figures 18 and 22, reflect a degradation in performance as a result of the VCG audio enhancement. These subjects made posttest comments that the audio was very disturbing and distracting to them during the

exposure. Subject #7, shown in Figure 24, shows a marked increase in performance with VCG Audio over the postrun results. This subject also expressed a posttest dislike for the audio cues.

The average scores for all test subjects versus frequency obtained during Phases III and IV Vibration Testing, are shown in Figure 26. The increased performance level over all frequencies due to the VCG Audio enhancement is immediately apparent. The addition of vibrational stimuli in Phase III appears to have degraded performance below Phase I and II results due to the vibrational stress duration function. The performance in Phase IV, however, has been enhanced above Phases I and II results. Considering the run sequence of increasing frequency from 5Hz. to 50 Hz. with no VCG Audio in Phase III, followed by a reduction in frequency from 50 Hz. to 5 Hz. with VCG Audio, in Phase IV, the trend is one of increasing performance over the twenty minute test period. Although these increased levels of performance with time reflect learning-dependent function trend, the rate of increase during Phase IV exceeds that level attributed to learning alone. Again, it can be summarized that the VCG Audio enhancement markedly improved the performance factor during the vibrational mode of tracking.

Further examination of the subject averages in Figure 26 and subject composites, as shown in Figures 27 through 30, reveals two distinct dips at 10Hz. and 25-30 Hz. The dip at 10 Hz. can be attributed to the inherent whole cockpit response at that frequency. This phenomenon was visually apparent during all test runs. The dip at 25 to 30 Hz. supports a similar result reported in a previous thesis on a study of the vibration

effects using a rigid control stick [Ref. 5]. This report suggested that the dip was caused by a large relative movement between head and shoulder coupled with a visual acuity problem caused by eyeball resonance within the orbital cavity near this frequency. Seven out of the nine test subjects reported this frequency as uncomfortable.

Figures 31 through 38 show the individual Vibration Testing Response graphs. Every subject shows a significant increase in performance over the frequency test band with VCG Audio.

C. SUMMARY

The significant results of all the testing are more readily apparent in an average phase response versus time graph as shown in Figure 39. The independent variables are (1) time of exposure, (2) with or without VCG Audio, and (3) with or without vibration. θ_1 on the graph represents the non-linear expected performance rate increase due to the exponential learning-dependent function. θ_2 represents the linear performance rate increase due to VCG Audio enhancement. θ_3 represents an increase in performance that is attributed to an elevated alertness factor due to vibrational stimuli, i.e., a positive vibration/alertness couple.

Phase I shows the expected increase due to the learning dependent function. The increase in performance during Phase II appears to be a two-dimensional response of both the learning-dependent function and the VCG Audio enhancement factor. The decrease in performance during Phase III below the expected learning response, shown in Figure 39 as D_1, is attributed to the negative biomechanical aspects of vibration exposure in conjunction with an apparent decreased alertness factor, i.e.,

a negative vibration/alertness couple. The increase in performance rate during Phase IV is a three-dimensional response of, (1) the learning-dependent function, (2) the VCG Audio enhancement factor, and (3) the enhanced alertness factor due to the positive vibration/alertness couple. Phase V, like Phase I, is simply a function of the exponential learning-dependent response.

Two main points of significance are (1) the degradation of tracking performance when exposed to vibrational stress exhibiting the expected negative vibration/alertness couple, and (2) the apparent enhancement of tracking performance when exposed to vibrational stress with audio feed-back cuing exhibiting an unexpected positive vibration/alertness couple.

V. CONCLUSIONS AND RECOMMENDATIONS

The primary aim of this study was to examine pilot performance and response to vibrational stress induced by mechanical whole body vibration and to establish the degree of performance degradation due to the vibration/alertness couple. Once the negative aspects of vibration in tracking task performance were substantiated, the effectiveness of aural feedback cuing was analyzed.

Analyses of the results leads to the following conclusions:

- There was evidence of statistically significant impairment in performance of the tracking task to test alertness, in comparison with the control conditions (without vibration). These findings are not unexpected and establish the validity of the negative vibration/alertness couple.

- The learning-dependent improvement in performance, depicted in the training tests as an exponential function over the training period, shows in the reliability analysis as increasing reliability with increasing duration of training. The relative high degree of initial performance at the commencement of the scoring runs followed by the mild slope of the exponential learning curve during the runs, is attributed to the pretest familiarization training. There is a risk here of falsifying effects superimposed by learning, which are solely interpreted as a change in long-term attentiveness.

- As is to be expected, reliability in performance declines as a function of the duration of the activity. Although no conclusive study

was performed to analyze this phenomenon, related data in the non-vibrational regime proves supportive after only two minutes of exposure time. The increased drop in performance towards the end of the test period is clear.

- As expected, frequency of vibration also proves to be a factor affecting reliability in the sense that under certain cyclic stimuli intensities, performance related responses showed significant decreases or dips. Some possible contributing factors are involuntary movement of the whole-body, and visual problems at certain frequencies.

- There was evidence to support the favorable addition of aural stimuli as an alertness enhancement component. The degree of improvement proved to be relatively linear across both the non-vibrational and vibrational regimes. In the vibrational regime, however, not only was the linear aural enhancement factor evident, but there was reversal of influence in the vibration/alertness couple. It was expected from the non-vibratory response, that the VCG audio would partially arrest the impairment in performance due to the negative vibration/alertness couple. The results, however, show a complete reversal in affect providing a positive vibration/alertness couple as a result of audio feedback cuing.

The benefit of enhanced performance while being involuntarily subjected to adverse conditions of mechanical whole body vibration by simply providing audio cues of relative success, in conjunction with the unexpected linear increase of reliability with vibration stress duration above non-vibrational modes, is heretofore undocumented. The significance of this anomaly is interesting at least.

It is too bold to suggest, that vibrational stimuli with audio-detected-success cues be purposely incorporated in any dynamic tracking system to enhance the degree of success, without further investigation. The following recommendations are made:

- Further research be conducted to ascertain the validity of audio-feedback cuing as a reliability enhancement factor. This study should include a broader base of subject data with statistically significant backgrounds.

- Extend the duration of exposure with and without audio feedback cuing to determine the long-term limits of performance under the adverse influence of vibration.

- Design different methods of testing alertness while exposed to vibrational stimuli, other than tracking tasks, and ascertain the validity of aural-feedback cuing in these tasks.

At least partial verification of this suspected relationship is the subject of this work. Further study would enable not only more general statements to be made on the effect of stress due to the environmental vibration factor, but also indications to be derived on general unspecific effects of the aural enhancement factor on performance. Finally, this would open up means of predicting and controlling performance under adverse conditions and solving practical problems of occupational exposure of aircraft to turbulent mediums.

APPENDIX A

LIST OF EQUIPMENT

1. Flight Simulator

   F4B Aircraft Cockpit Procedures Trainer,

   Device 2C30 (modified)

   Burteck, Inc.

2. Analog Computer

   PACE TR-10

   Electronics Associates, Inc.

3. Tape Deck

   ALPHA 434 (One-quarter inch, reel-to-reel, 4 track)

   Midwestern Instruments

4. X-Y Display

   Model 1300A

   Hewlett-Packard Co.

5. Oscilloscope

   Model T922

   Tektronix, Inc.

6. Test-Tape Control Unit

7. Signal Control Box

8. Electrostatic Recorder (8-track)

   Model Statos 3

   Varian Data Machines

9. Digital Multimeter

   Series 8300

   California Instruments Corporation

10. Frequency Counter

   Model 100A

   Monsanto Electronics

11. Variable Controlled Generator (VCG)

   Model 145

   Wavetec

12. Audio Amplifier

   Model MX60A

   LSI, Bogen Division

13. Headsets

   Model 1210

   Telex Corporation

14. Shaker Table and LTV Servo Control System

   Model 219

   Calidyne/Ling Electronics, Inc.

15. Accelerometer

   Model 3366

   Statham Laboratories

APPENDIX B

TRANSCRIPT OF TAPED BRIEFINGS AND INSTRUCTIONS

- You now see the zero signal on the Dynamic-Response Scope in front of you. Your objective in this exercise will be to keep the pip within one centimeter of the zero position for weapon acquisition. The control stick will be moved for aileron and rudder response in such a manner as to intercept a visual target.

Following are three trial tasks designed to familiarize you with the proper response necessary for successful tracking. The first run represents a vertical separation of the target, followed by the second run which represents a horizontal separation of the target, and finally, the third run represents a two-axis separation of the target. You will be aurally cued to the start and finish of each run. Your objective in all three runs will be to keep the pip centered on the scope.

- Standby for the vertical trail tracking task. The trial will begin on my third Now.

Begin task Now, Now, Now!

- That completes the vertical trial tracking task.

- Standby for the horizontal trial tracking task. The trial will begin on my third Now.

Begin task Now, Now, Now!

- That completes the horizontal trial tracking task.

- Standby for the two-axis trial tracking task. The trial will begin on my third Now.

Begin task Now, Now, Now!

- That completes the two-axis trial tracking task.

- The next part of this exercise will be scored based upon your ability to maintain target acquisition by keeping the pip within one centimeter of the center-position on the Dynamic Response Scope. If you have any questions, now is the time to ask. The test will begin in approximately one minute.

- Standby for the target acquisition scoring run. The exercise will begin on my third Now.

Begin exercise Now, Now, Now!

APPENDIX C

SETUP AND ALIGNMENT PROCEDURE

1. Master Circuit Breaker - ON
2. Remote Dynamic Response Scope (RDRS) - ON, Intensity set, Pip centered
3. Aural Tracking Monitor Control Amplifier - ON, Master gain set
4. Tape Deck - ON, slow speed, counter reading of 020
5. Analog Computer - ON, Reset position
6. 8-Track recorder - MON
7. VCG - ON, Frequency 100 Hz. set
8. Frequency Counter - ON, Reset
9. Shaker Table Control - ON/STAND BY (See Shaker table operation instructions)
10. Dynamic Response Scope (DRS) - ON, Intensity set, Pip centered
11. Energize Cockpit - Ganged three-phase switch, Start, 12V power
12. Centered cockpit stick for STAB TRIM NEUTRAL and AIL TRIM NEUTRAL lights.
13. Analog Computer - OPER
    - OVLD lights out
    - Adjust Long. zero (P-10) for OV on amplifier 12-lower output
    - Adjust Lat. zero (P-12) for OV on amplifier 18-upper output
14. Readjust the DRS and RDRS pips to center position

APPENDIX D

SIMULATOR RESPONSE

PROJECT INTERVIEW QUESTIONNAIRE

PRETEST:

Name______________________________ Test Run No. __________

Rank______________________________ Date __________

Duty Station________________________

Designator__________________________

Warfare Specialty____________________

Total Pilot Hours____________________

Latest aircraft model flown____________

Hours in latest model flown____________

POSTTEST

What portion of the test presented the greatest difficulty in tracking performance?____

____

Did the audio indication of off-track performance help in the tracking task?____

____

Did the audio reinforcement help your performance in the cockpit-vibration portion of the test?____

____

____

Would you recommend an audio tracking option be available on inflight target-tracking equipment?____________________________________

____

____

COMMENTS: ____

APPENDIX E

TESTING PROCEDURE

1. Pilot in cockpit with headphones donned
2. Secure black-canvas canopy
3. 8-Track Recorder - RECORD, Chart Speed - 0.5 cm/sec, Time Interval - 1 sec.
4. Start tape deck, Counter reading of 100
5. Familiarization Phase:
   - A. Vertical Trial Tracking Task (55 secs.)
   - B. Horizontal Trial Tracking Task (50 secs.)
   - C. Two-axis Trial Tracking Task (155 secs.)
6. Phase I - Five minute tracking training period
7. Phase II - Five minute tracking period with VCG Audio
8. Phase III - Ten minute tracking period with vibration; All periods 1 minute duration, PA-1 = 0.4 amps constant

Frequency (Hz.)	G-Level	Frequency (Hz.)	G-Level
5	0.16	45	0.60
10	0.15	50	0.58
15	0.11		
20	0.10		
25	0.17		
30	0.25		
35	0.58		
40	0.65		

9. Phase IV - Ten minute tracking with vibration and VCG audio; all periods 1 minute duration; PA-1 = 0.4 amps constant

Frequency (Hz.)	G-Level
5	0.16
10	0.15
15	0.11
20	0.10
25	0.17
30	0.25
35	0.58
40	0.65
45	0.60
50	0.58

10. Phase V - Five minute tracking period

11. Stop Test, all equipment to standby

APPENDIX F

SIMULATOR RESPONSE

DATA ANALYSIS FORM

Name____________________ Test Run No. ____________

Date ____________

		Score
I.	Familiarization Phase	
	A. Vertical Trial Tracking Task	____
	B. Horizontal Trial Tracking Task	____
	C. Two-Axis Trial Tracking Task	____
II.	Phase I: Negative Vibration Pretest Baseline	
	Time (Min.)	
	1	____
	2	____
	3	____
	4	____
	5	____
III.	Phase II: Negative Vibration with VCG Audio	
	Time (Min.)	
	1	____
	2	____
	3	____
	4	____
	5	____

IV. Phase III: Vibration Testing

Freq. (Hz.)	G-Load	Score
5		____
10		____
15		____
20		____
25		____
30		____
35		____
40		____
45		____
50		____

V. Phase IV: Vibration Testing with VCG Audio

Freq. (Hz.)	G-Load	Score
5		______
10		______
15		______
20		______
25		______
30		______
35		______
40		______
45		______
50		______

VI. Phase V. Negative Vibration Posttest Baseline

Time (Min.)	
1	______
2	______
3	______
4	______
5	______

APPENDIX G

RAW SCORES WITHOUT VIBRATION

Phase I: Without VCG Audio

TIME (MIN)	SUBJECT								AVERAGE
	1	2	3	4	5	6	7	8	
1	42	29	45	43	49	40	33	38	39.9
2	46	38	34	42	53	32	23	42	38.8
3	43	22	36	24	58	27	36	30	34.5
4	36	31	42	30	52	35	23	35	35.5
5	33	36	38	19	47	30	31	43	34.6
									36.7

Phase II: With VCG Audio

TIME (MIN)	SUBJECT								AVERAGE
	1	2	3	4	5	6	7	8	
1	26	42	48	37	53	40	38	41	40.6
2	28	38	47	38	49	49	40	44	41.6
3	20	35	40	35	53	48	46	42	39.9
4	20	34	38	32	45	38	45	40	36.5
5	30	42	34	29	39	42	39	40	36.9
									39.1

Phase V: Without VCG Audio

TIME (MIN)	SUBJECT								AVERAGE
	1	2	3	4	5	6	7	8	
1	51	50	42	54	60	49	41	56	50.4
2	59	51	59	55	57	56	39	55	53.0
3	43	51	57	55	60	56	42	54	52.3
4	54	50	50	45	57	52	30	58	49.5
5	52	49	50	47	52	51	43	52	49.5
									51.1

APPENDIX H

RAW SCORES WITH VIBRATION

Phase III: Without VCG Audio

FREQUENCY (HZ.)	SUBJECT								AVERAGE
	1	2	3	4	5	6	7	8	
5	27	20	23	30	33	36	33	27	28.6
10	29	21	26	21	43	30	28	20	27.3
15	33	27	28	30	31	34	33	32	31.0
20	32	28	38	22	40	32	34	37	32.9
25	24	32	31	21	42	35	25	22	29.0
30	31	43	45	34	31	46	27	38	36.9
35	35	28	37	38	60	34	35	30	37.1
40	41	42	32	28	35	37	34	24	34.1
45	31	25	28	29	42	39	24	50	33.5
50	47	36	33	29	35	38	26	27	33.9
									32.4

Phase IV: With VCG Audio

FREQUENCY (HZ.)	SUBJECT								AVERAGE
	1	2	3	4	5	6	7	8	
5	39	48	50	48	44	49	51	52	47.6
10	34	40	48	42	48	56	44	47	44.9
15	36	46	50	39	51	52	45	51	46.3
20	45	48	54	37	51	49	40	44	46.0
25	40	44	54	48	50	51	46	53	48.3
30	37	38	50	33	48	48	44	44	42.3
35	38	52	53	38	54	52	35	49	46.4
40	31	48	46	36	44	42	44	50	42.6
45	33	48	50	40	46	48	38	39	42.3
50	22	44	39	41	48	49	43	35	40.1
									44.7

APPENDIX I

TABLE I

SEQUENCE OF EVENTS ON THE TEST

PROCEDURES TAPE RECORDING

Tape Deck Counter Reading	Evolution
80	Start of Zero Signal (60 sec)
100	Voice Briefing Commences (60 sec)
120	Vertical Trial Tracking Task (45 sec)
135	Rest Period with Zero Signal (15 sec)
140	Horizontal Trial Tracking Task (45 sec)
155	Rest Period with Zero Signal (15 sec)
160	Two-Axis Trial Tracking Task (75 sec)
185	Rest Period with Zero Signal (75 sec)
210	ACM Test Sequence Begins (37 min)
950	End of Test Signal

TABLE II

TEST SUBJECT BACKGROUND SUMMARY

Subject Number	Status	Pilot (yes/no)	Type Aircraft	Total Hours
1	Professor of Aero (Civilian)	No	-----	-----
2	Aero Student (LT USN)	Yes	CH-46D	800
3	Technician (Civilian)	Yes	T-34	550
4	Aero Student (LCDR USN)	No (NFO)	P-3C	2000
5	Aero Student (LT USN)	Yes	SH-2F	805
6	Aero Student (LT USN)	No NFO	F-14	860
7	Aero Student (LCDR USN)	No NFO	F-14	700
8	Technician (Civilian)	Yes	T-34B	400
9	Professor of Aero (Retired Military)	Yes	T-28/S-2	7000

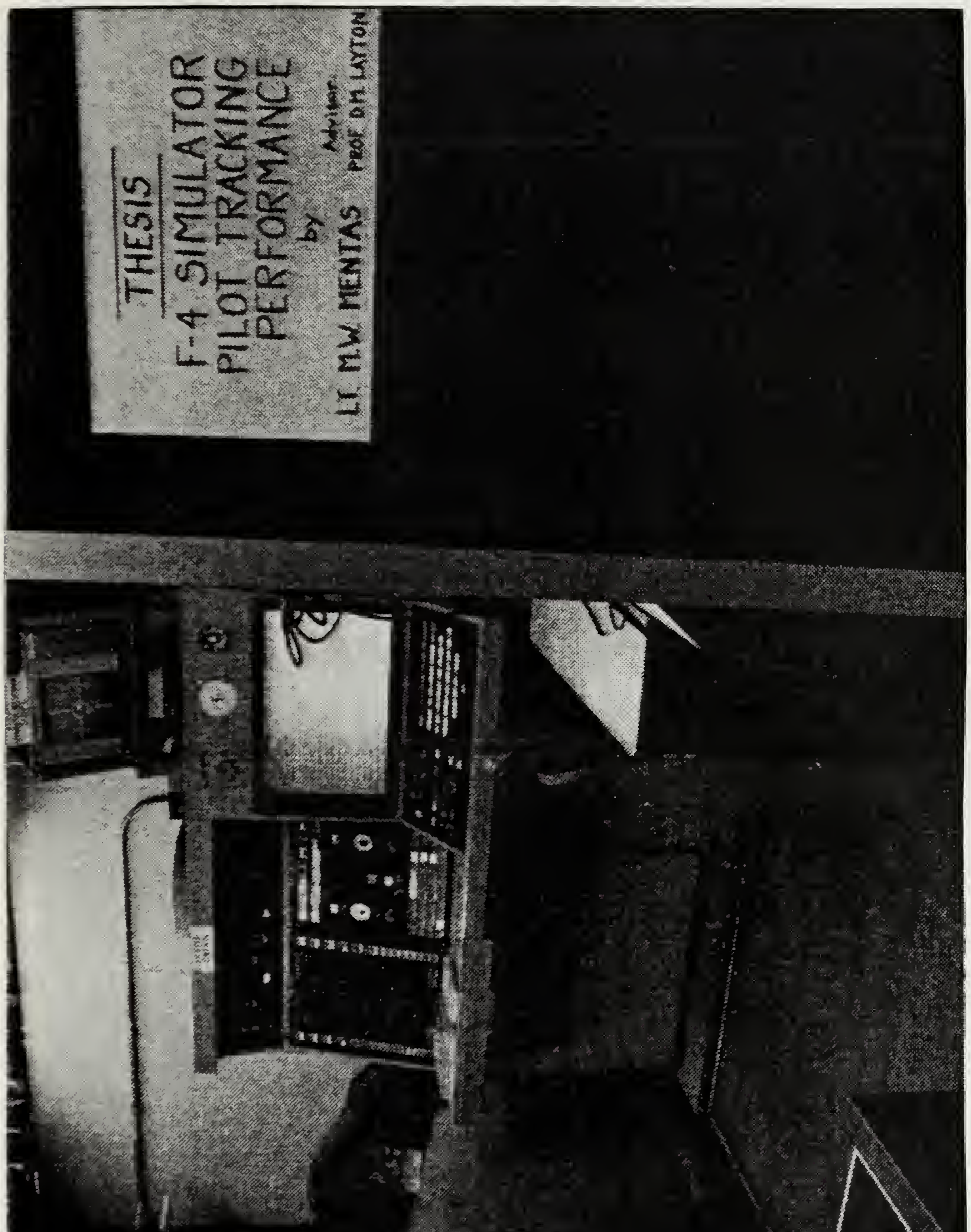

FIGURE 1. VIEW OF CONTROLLER'S CONSOLE AND COCKPIT

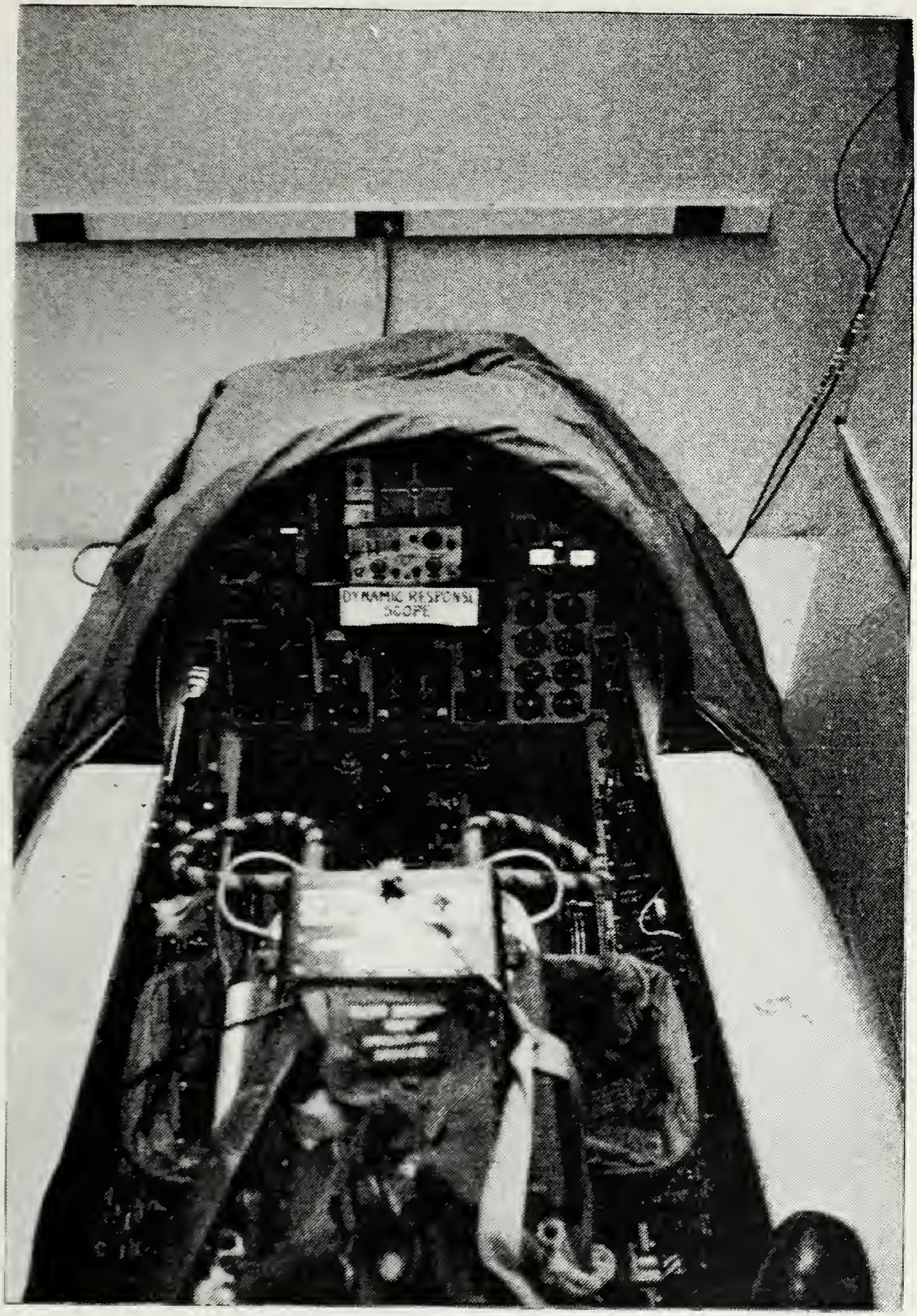

FIGURE 2. INTERIOR VIEW OF COCKPIT

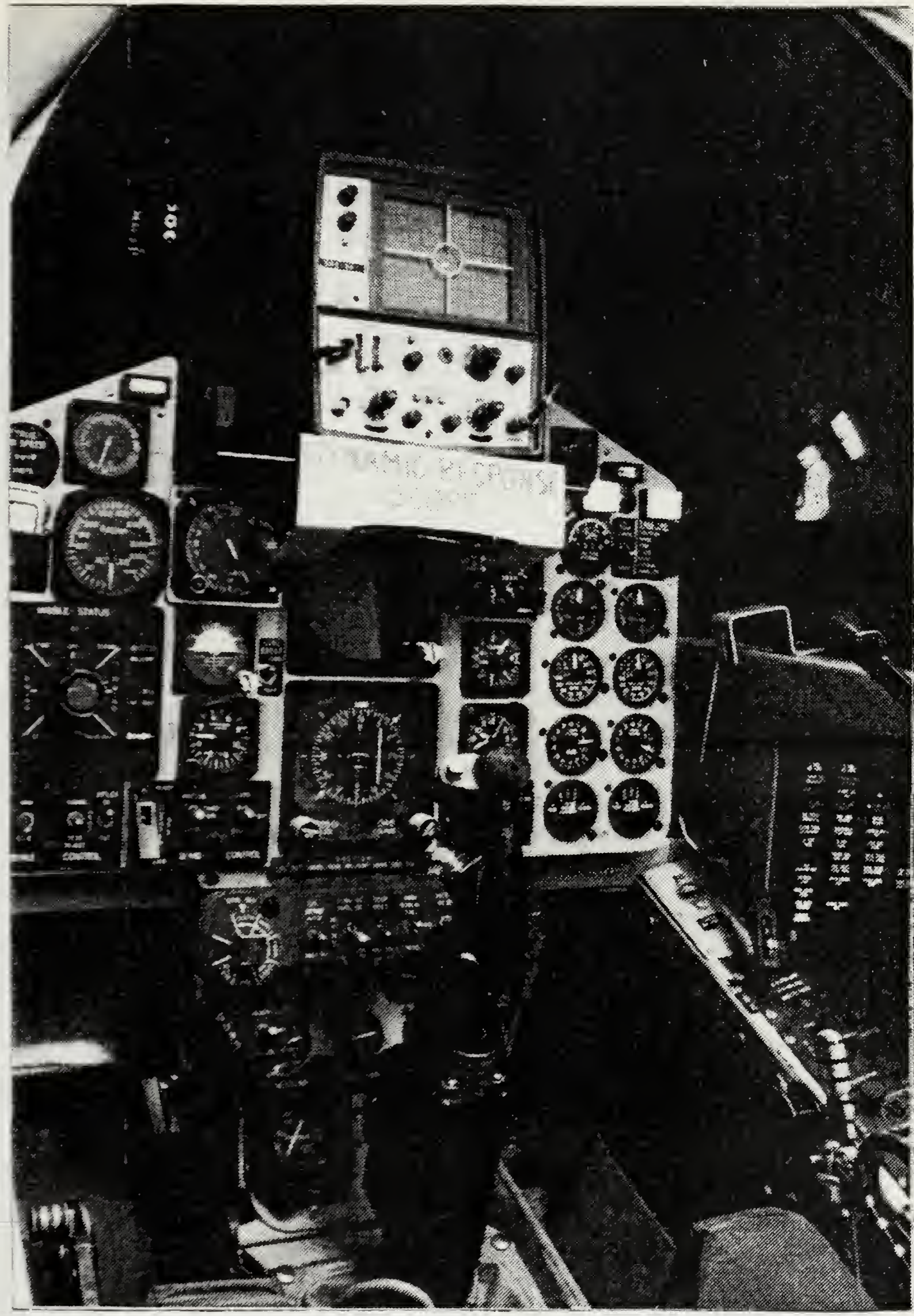

FIGURE 3. COCKPIT INSTRUMENT PANEL

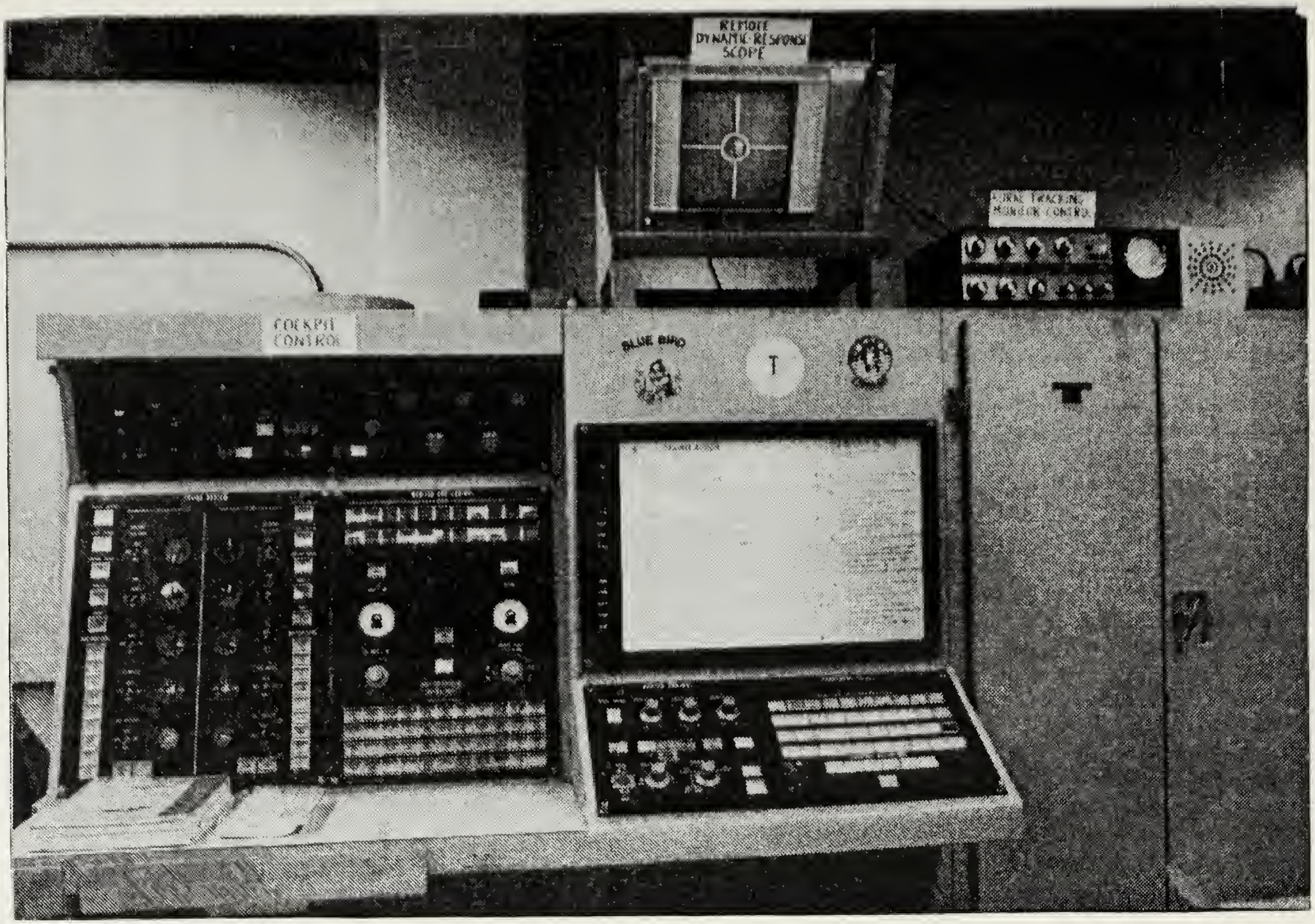

FIGURE 4. F4B COCKPIT PROCEDURES TRAINER CONTROL CONSOLE

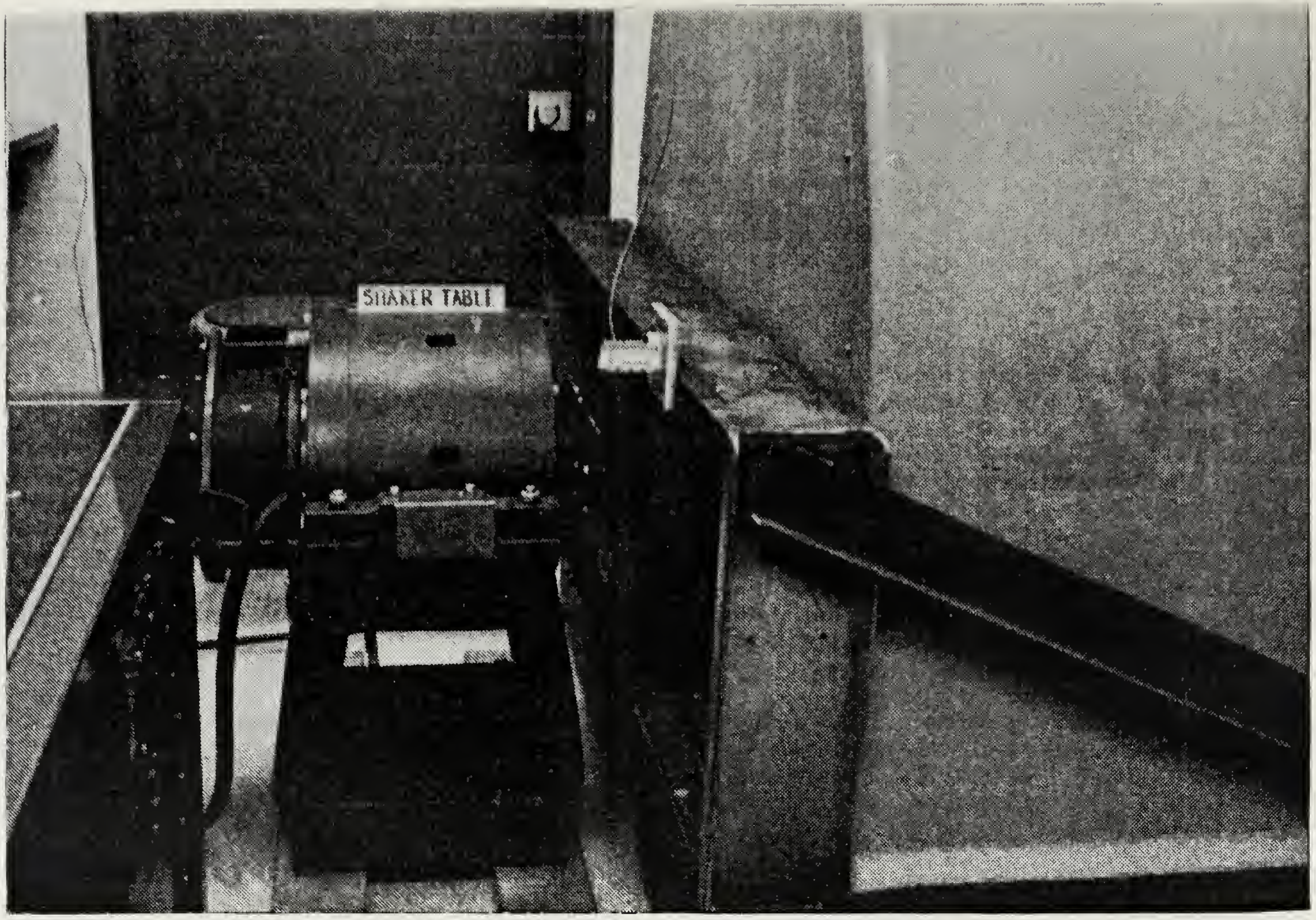

FIGURE 5. SHAKER TABLE AND COCKPIT INTERFACE

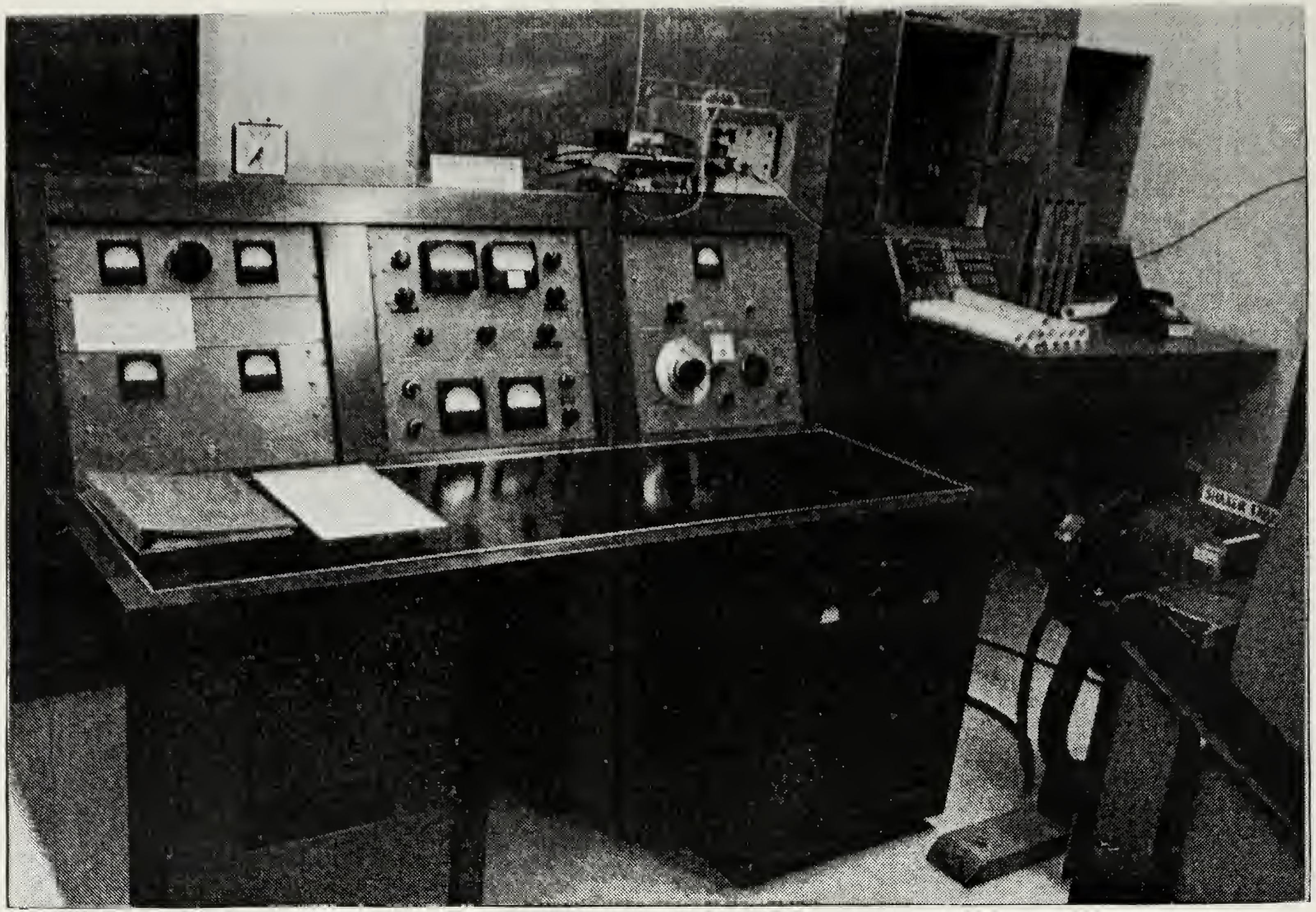

FIGURE 6. SHAKER TABLE CONTROL SECTION

FIGURE 7. VIEW OF CONTROLLER'S CONSOLE AND DYNAMIC CONTROL SECTION

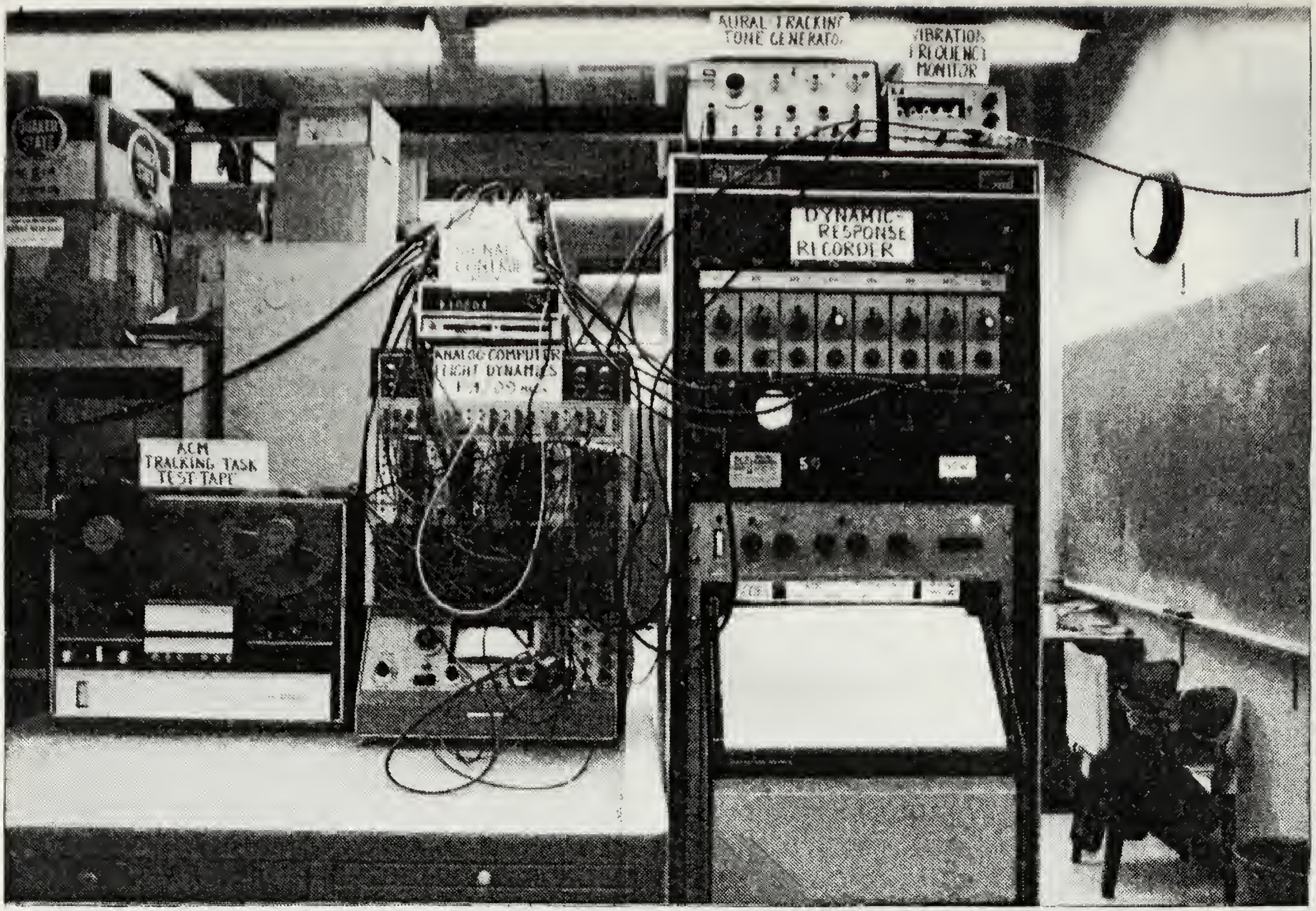

FIGURE 8. DYNAMIC CONTROL AND MONITOR SECTION

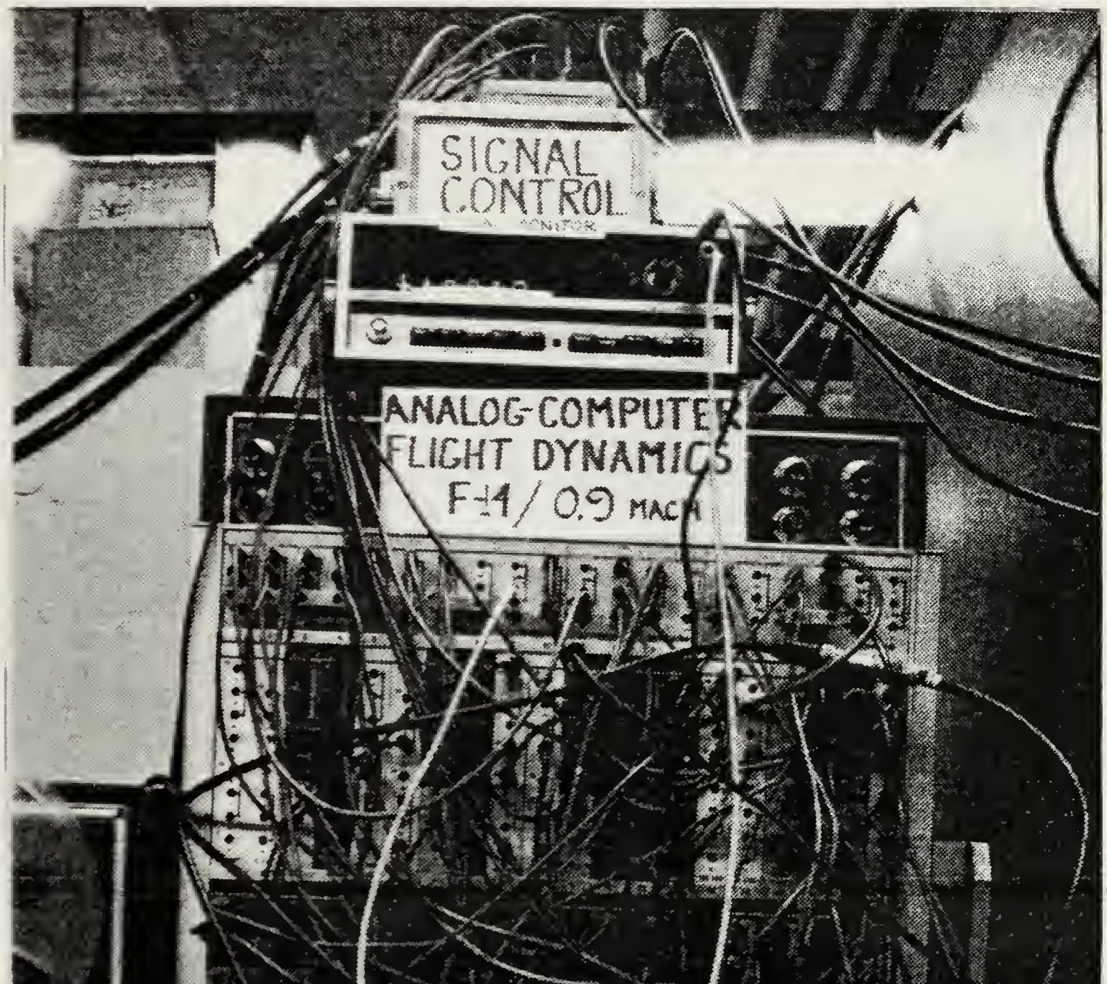

FIGURE 9. ANALOG DYNAMIC CONTROL SECTION

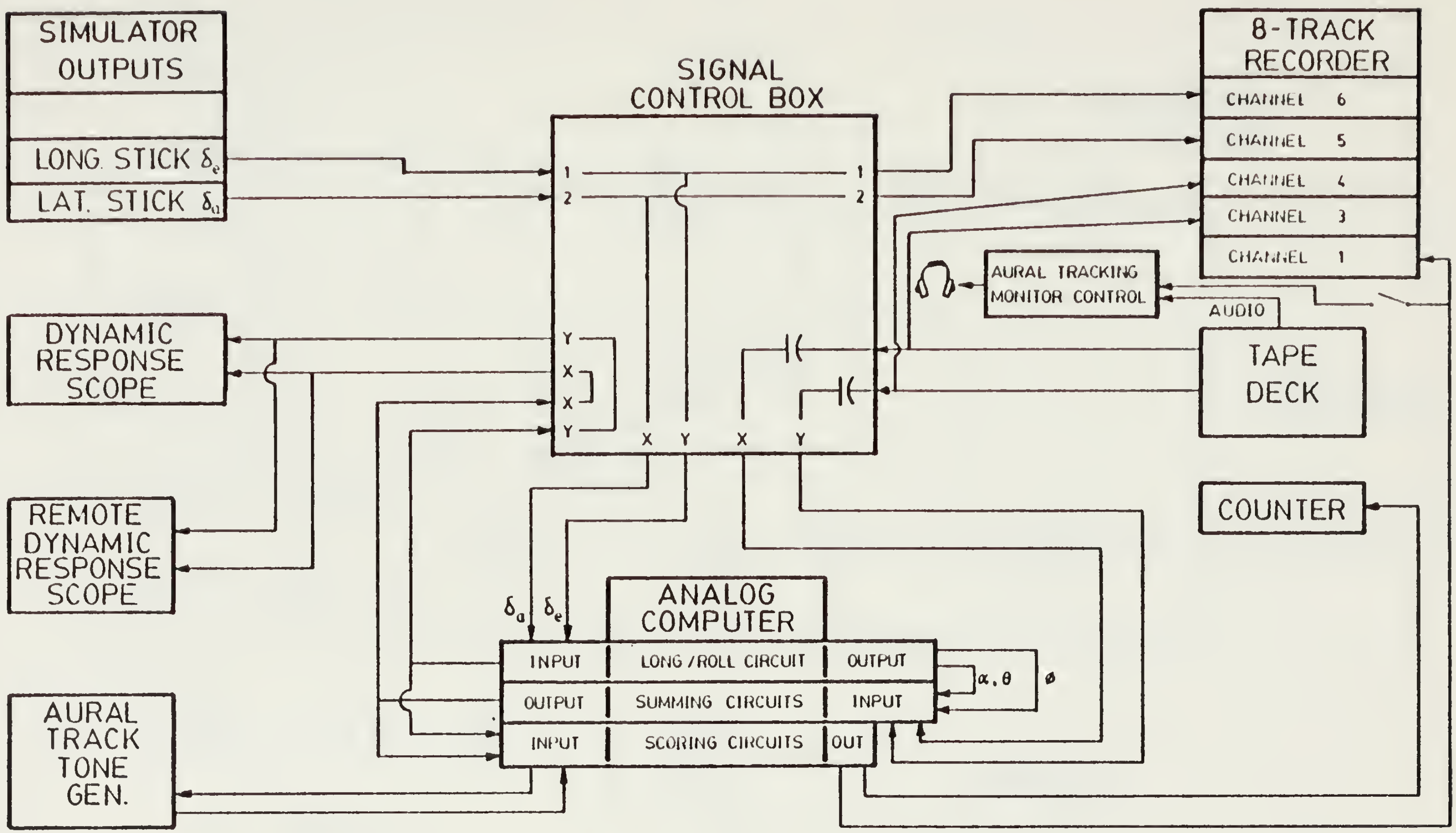

FIGURE 10. MONITOR AND CONTROL SYSTEM

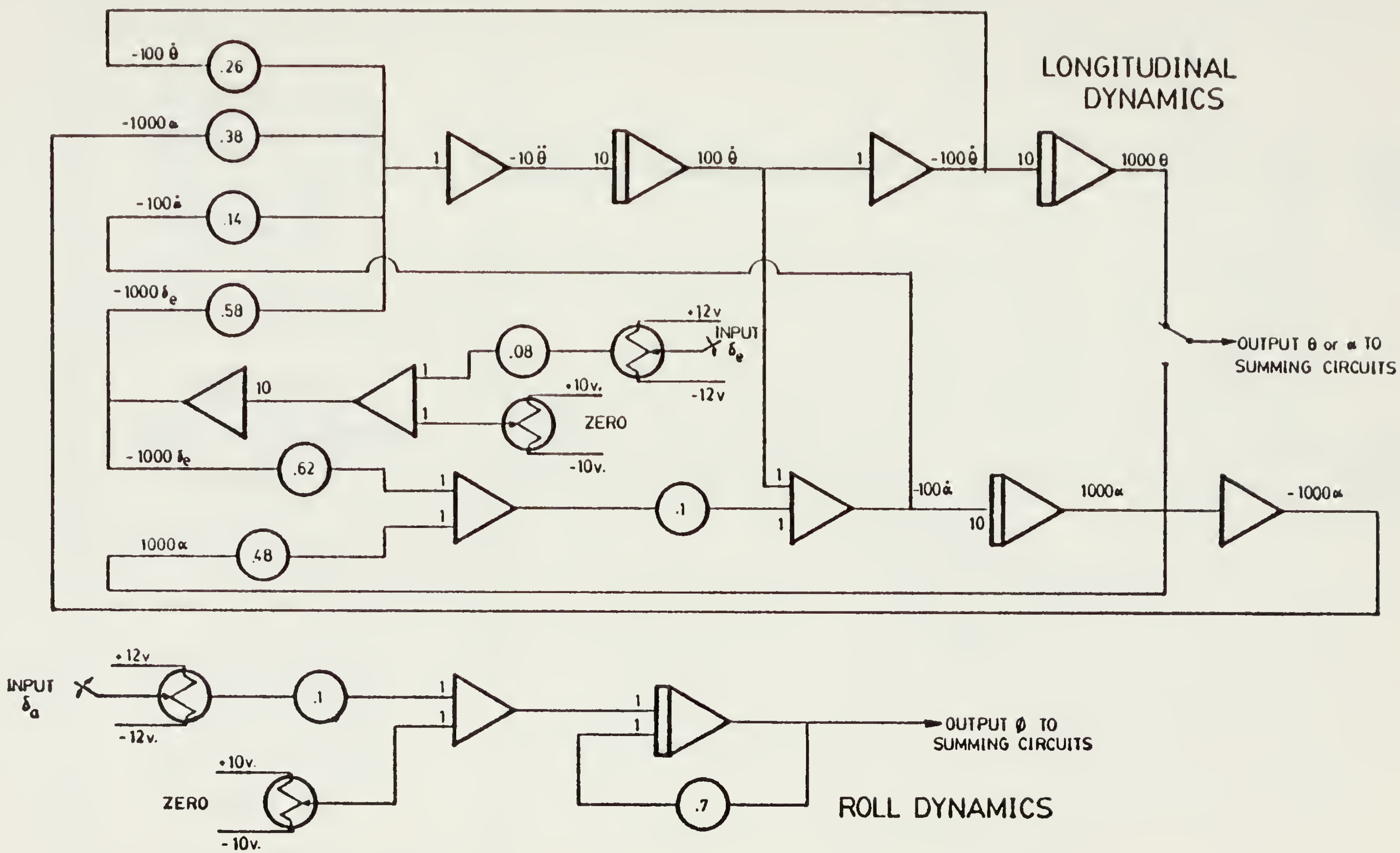

FIGURE 11. ANALOG COMPUTER LONGITUDINAL/ROLL CIRCUITS

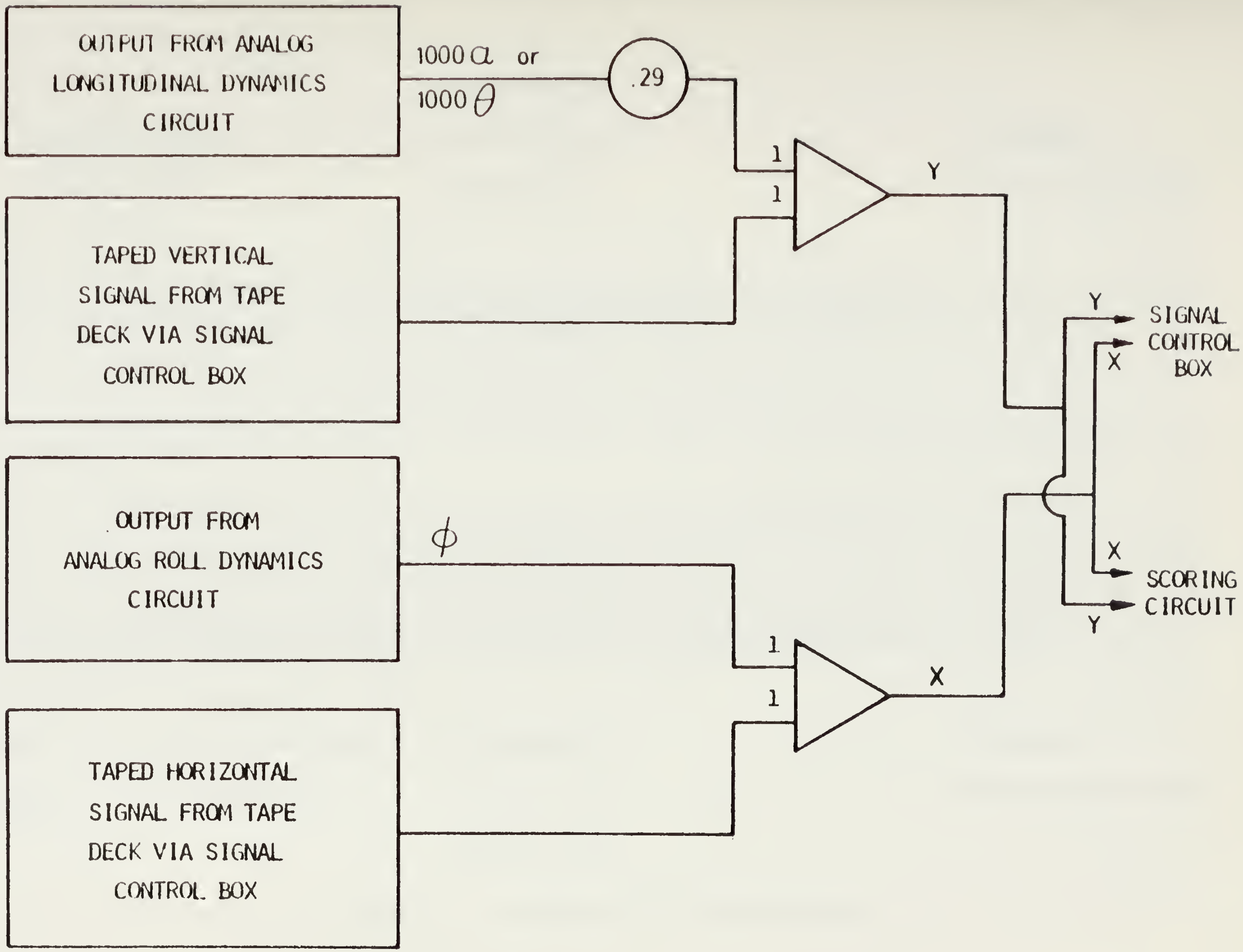

FIGURE 12. VERTICAL & HORIZONTAL SUMMING CIRCUIT

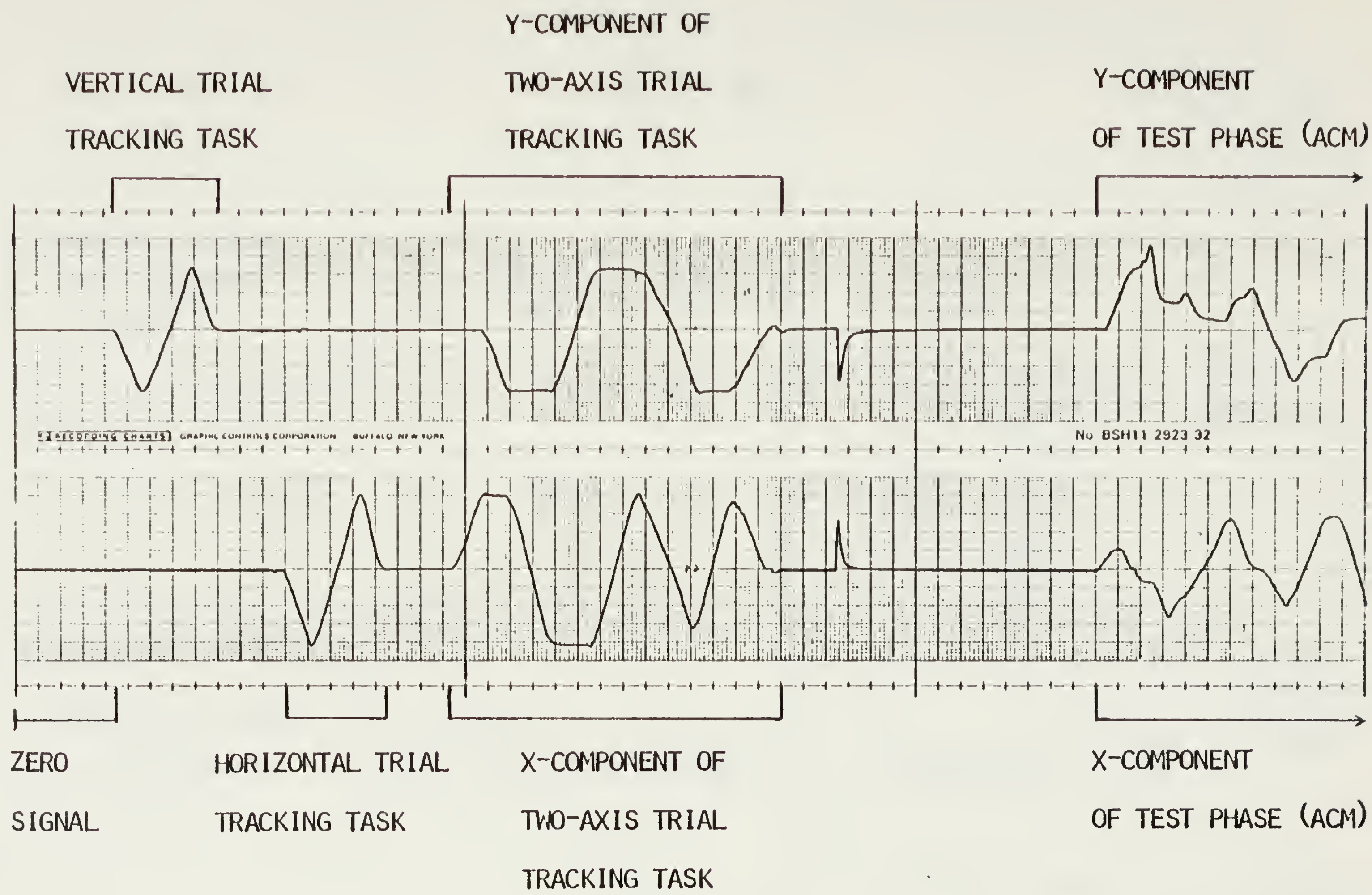

FIGURE 13. REPRODUCTION OF TAPED SIGNAL

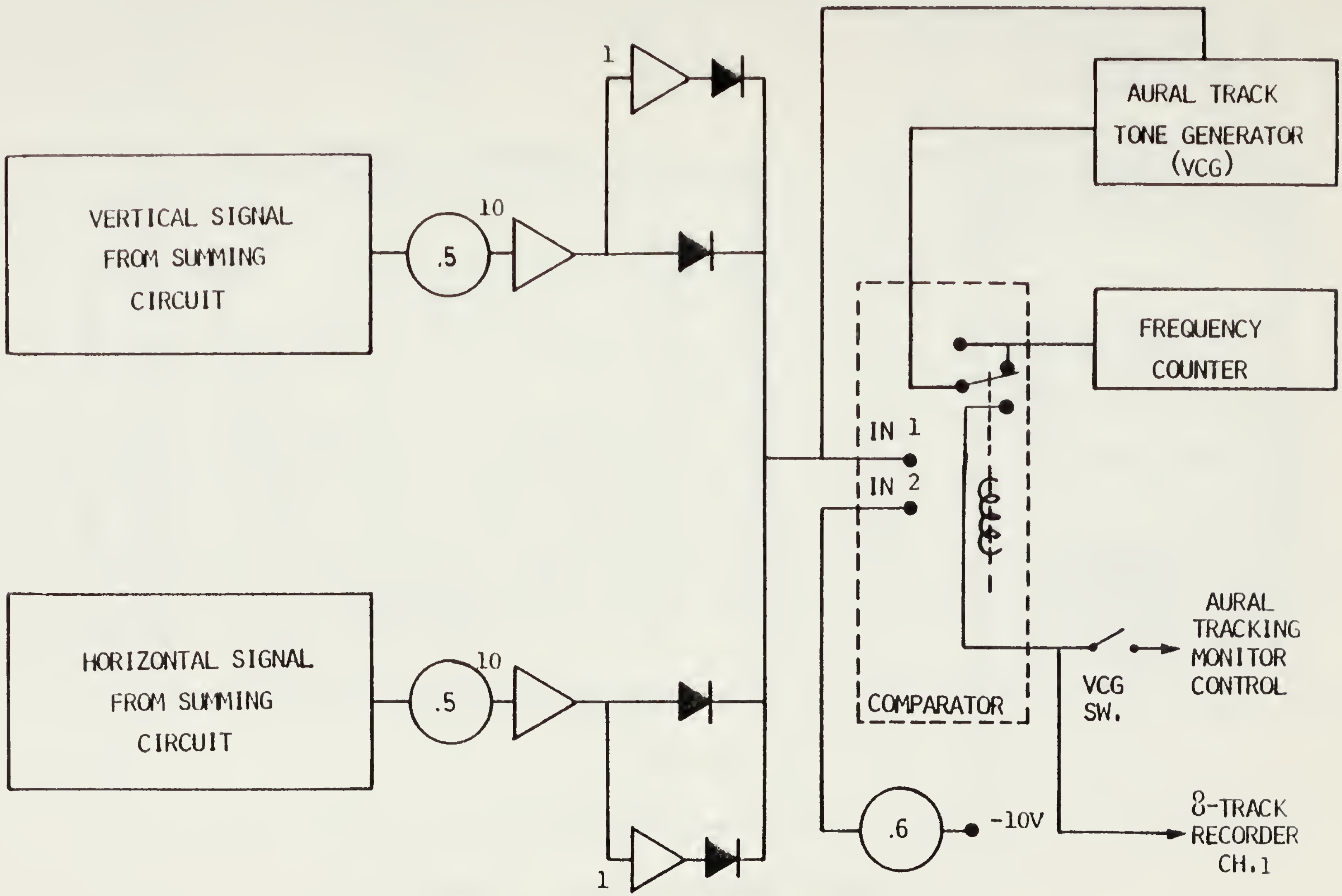

FIGURE 14. SCORING CIRCUITS

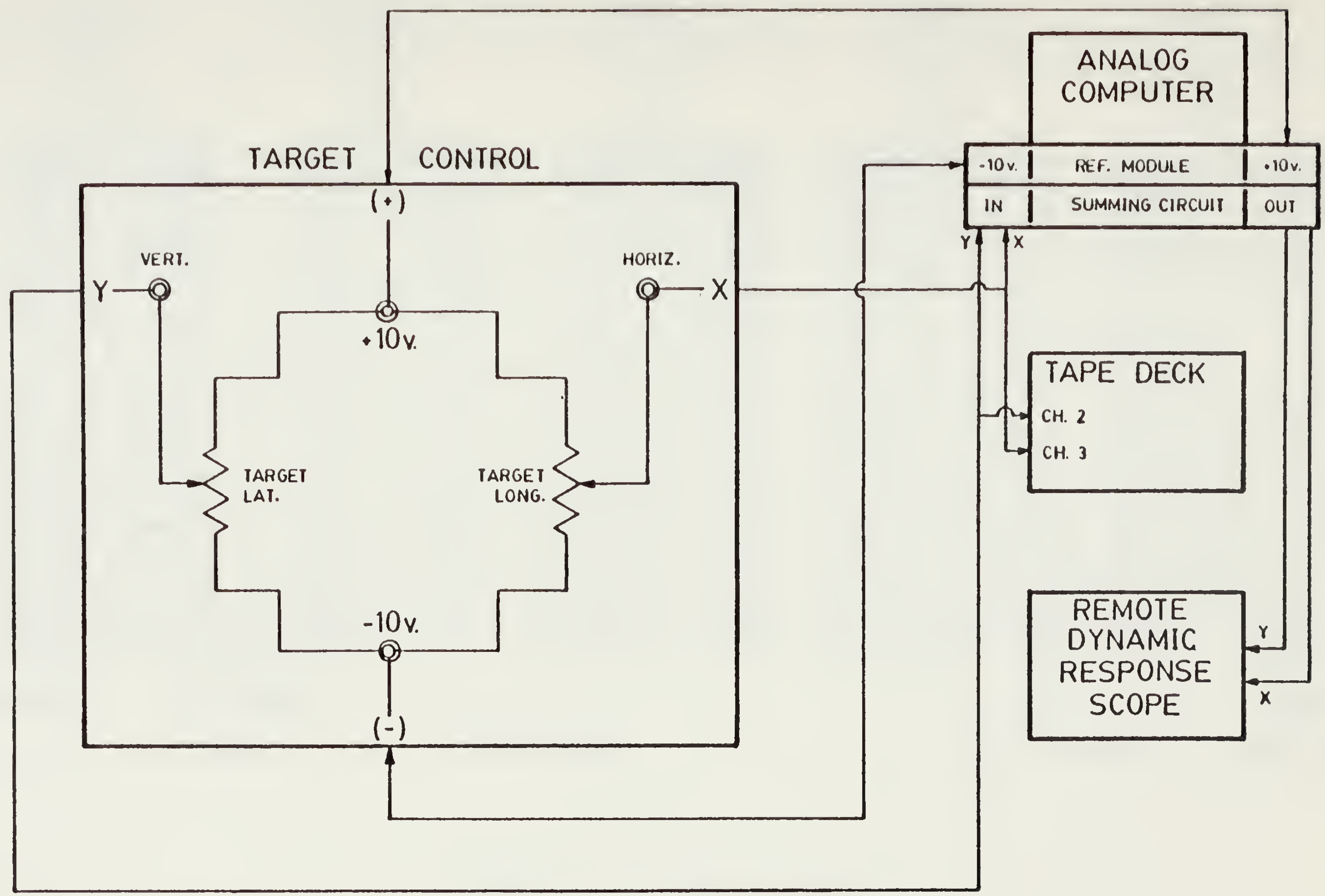

FIGURE 15. TEST TAPE CONTROL CIRCUIT

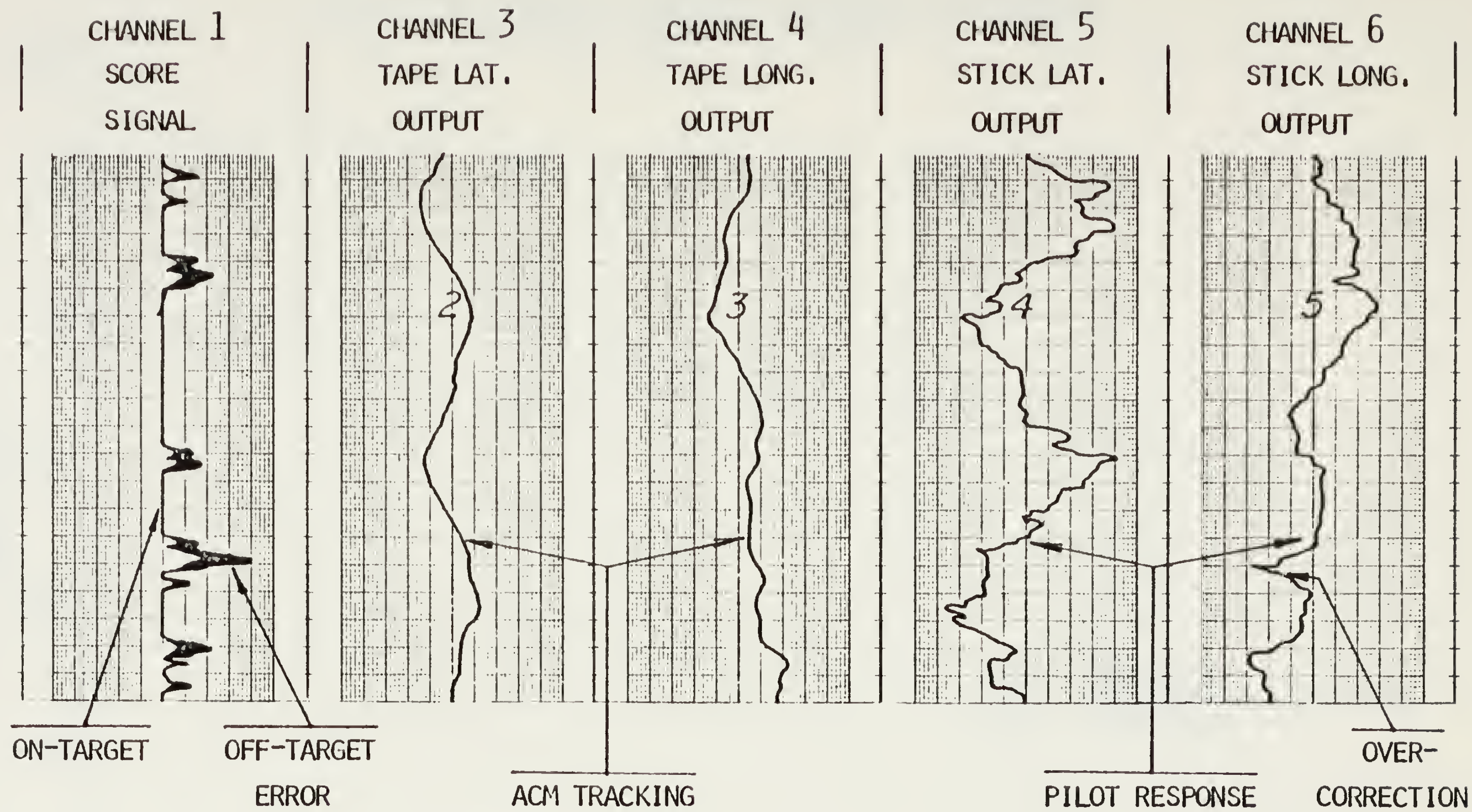

FIGURE 16. SAMPLE DATA RUN

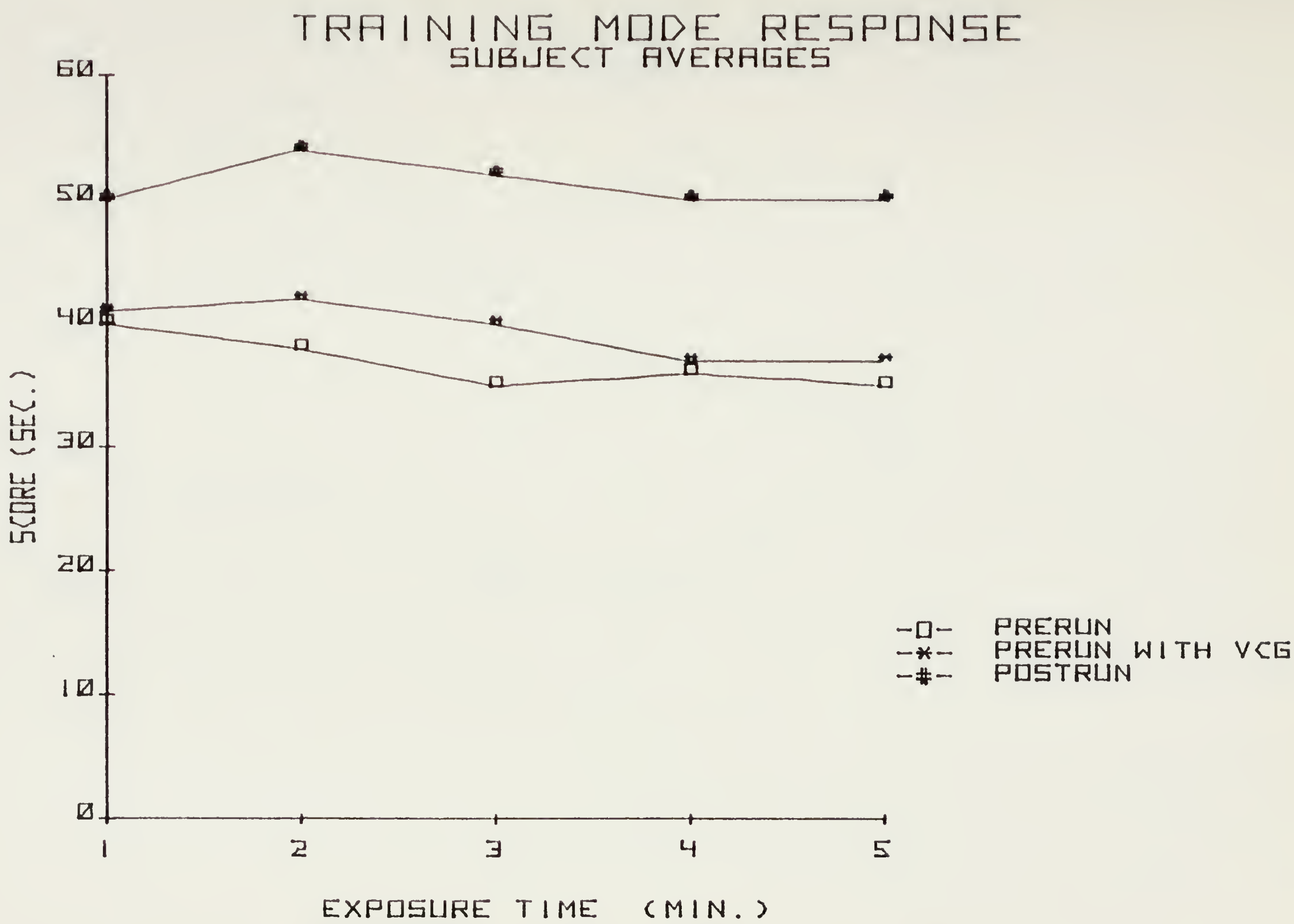

FIGURE 17. PHASE I, II, AND V AVERAGE SCORES

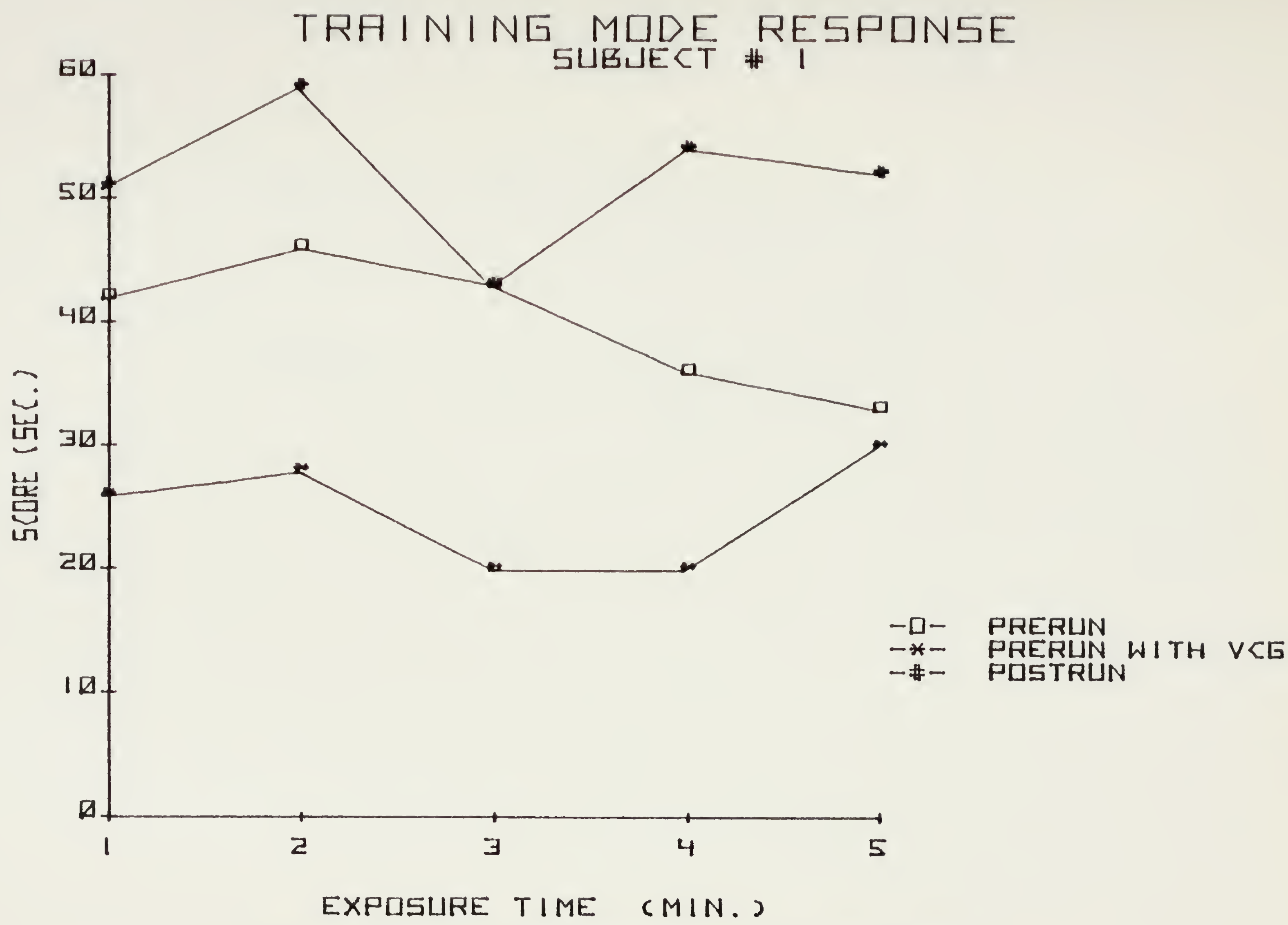

FIGURE 18. PHASE I, II, AND V SUBJECT #1 RAW SCORES

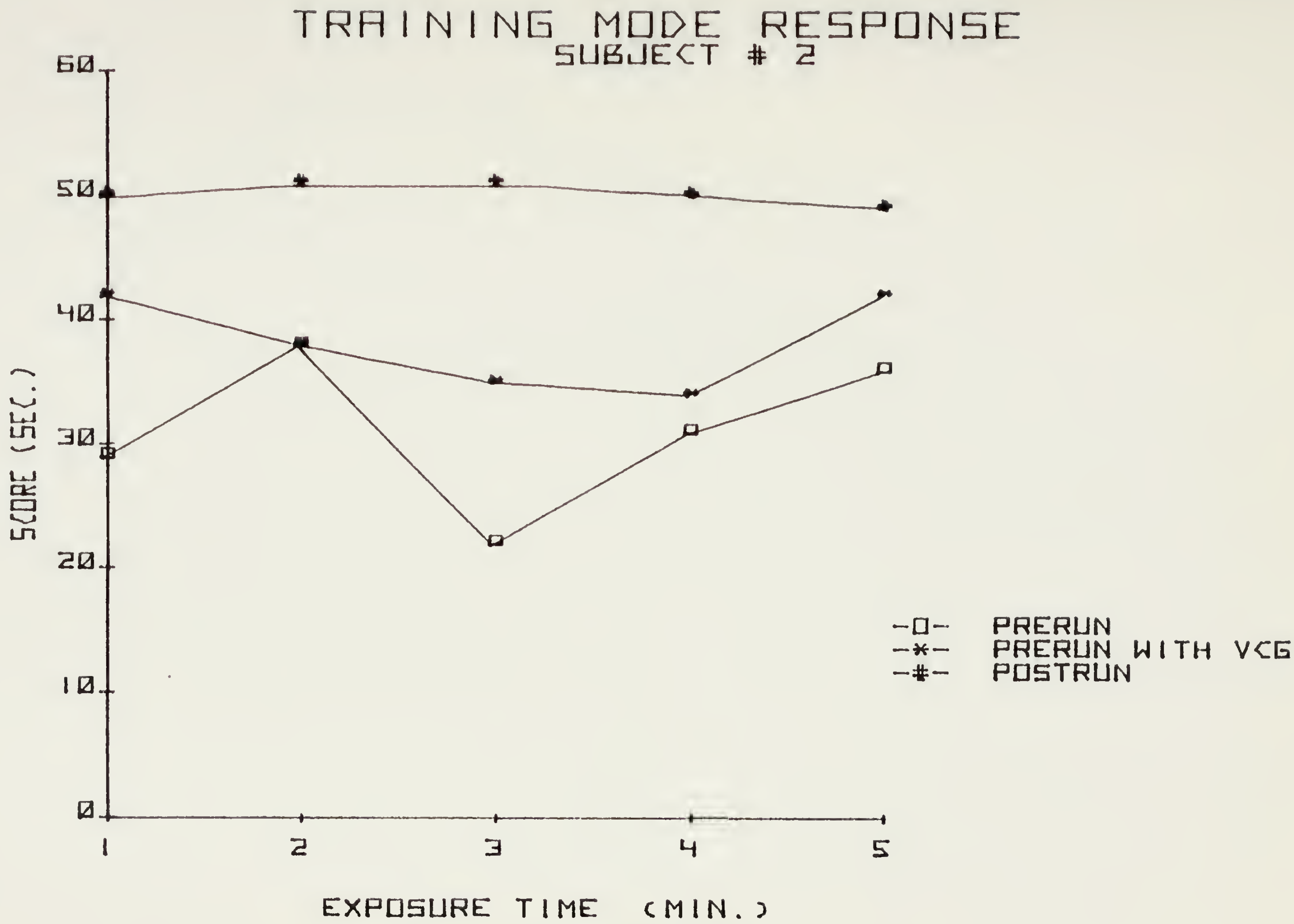

FIGURE 19. PHASE I, II, AND V SUBJECT #2 RAW SCORES

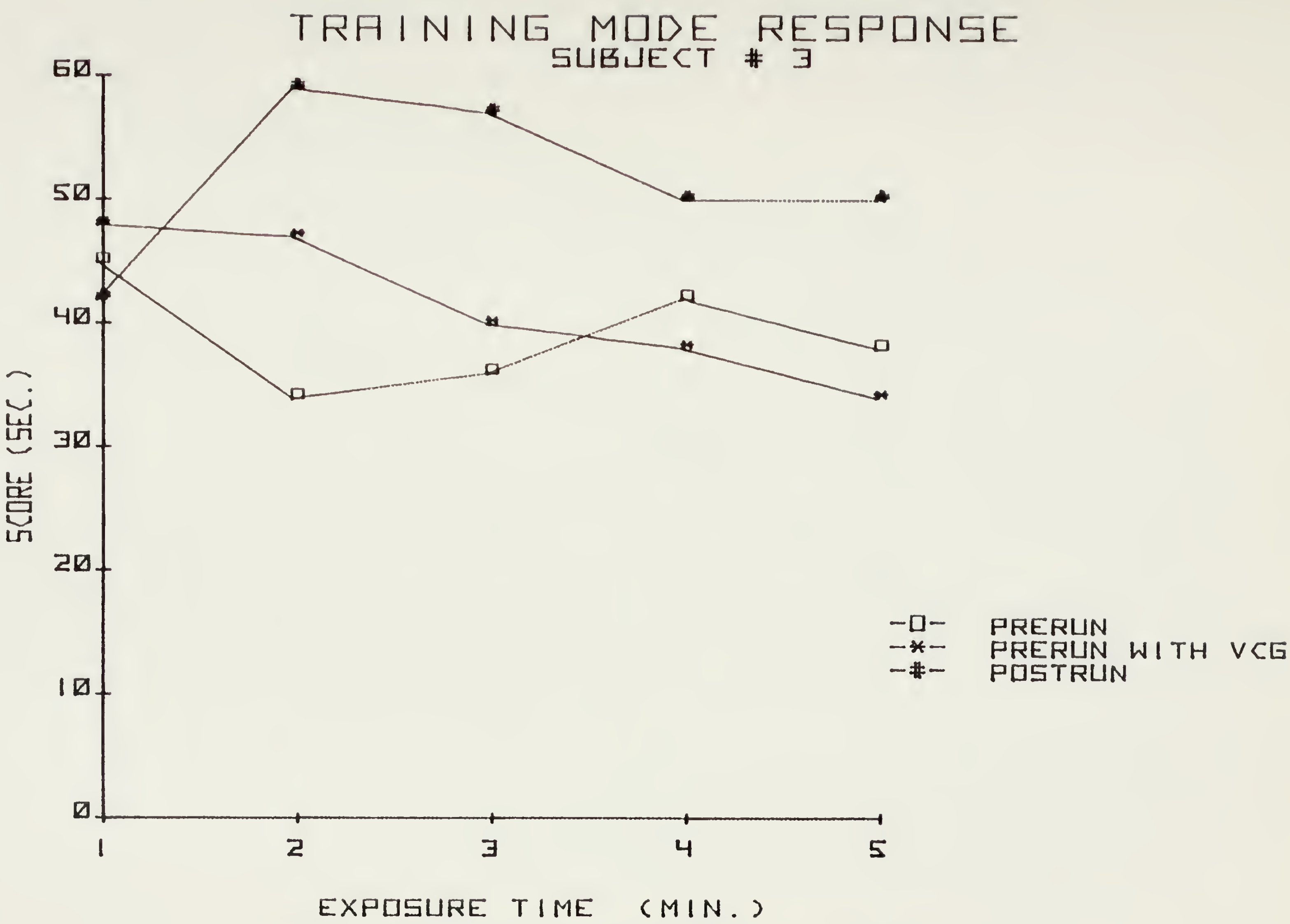

FIGURE 20. PHASE I, II, AND V SUBJECT #3 RAW SCORES

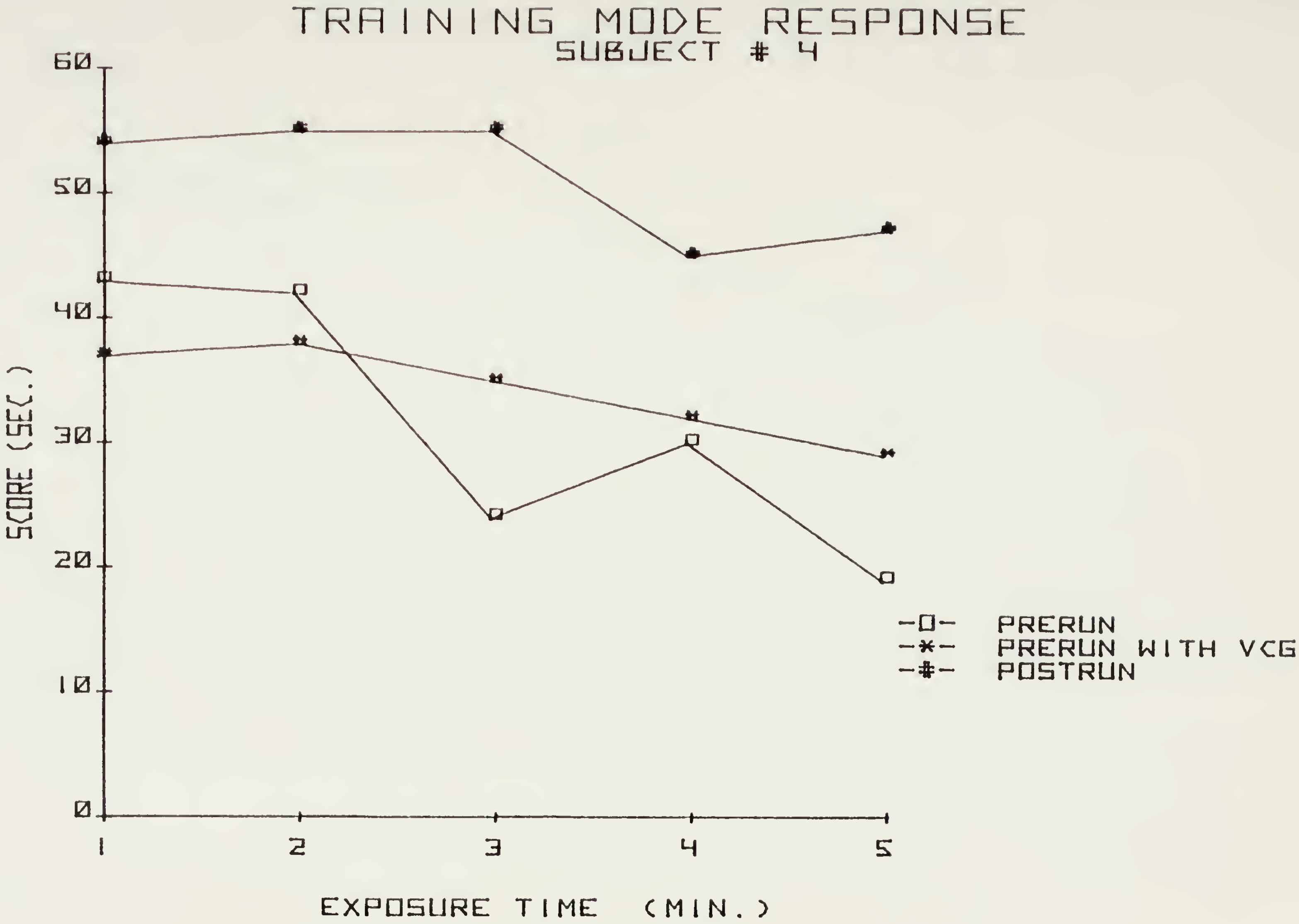

FIGURE 21. PHASE I, II, AND V SUBJECT #4 RAW SCORES

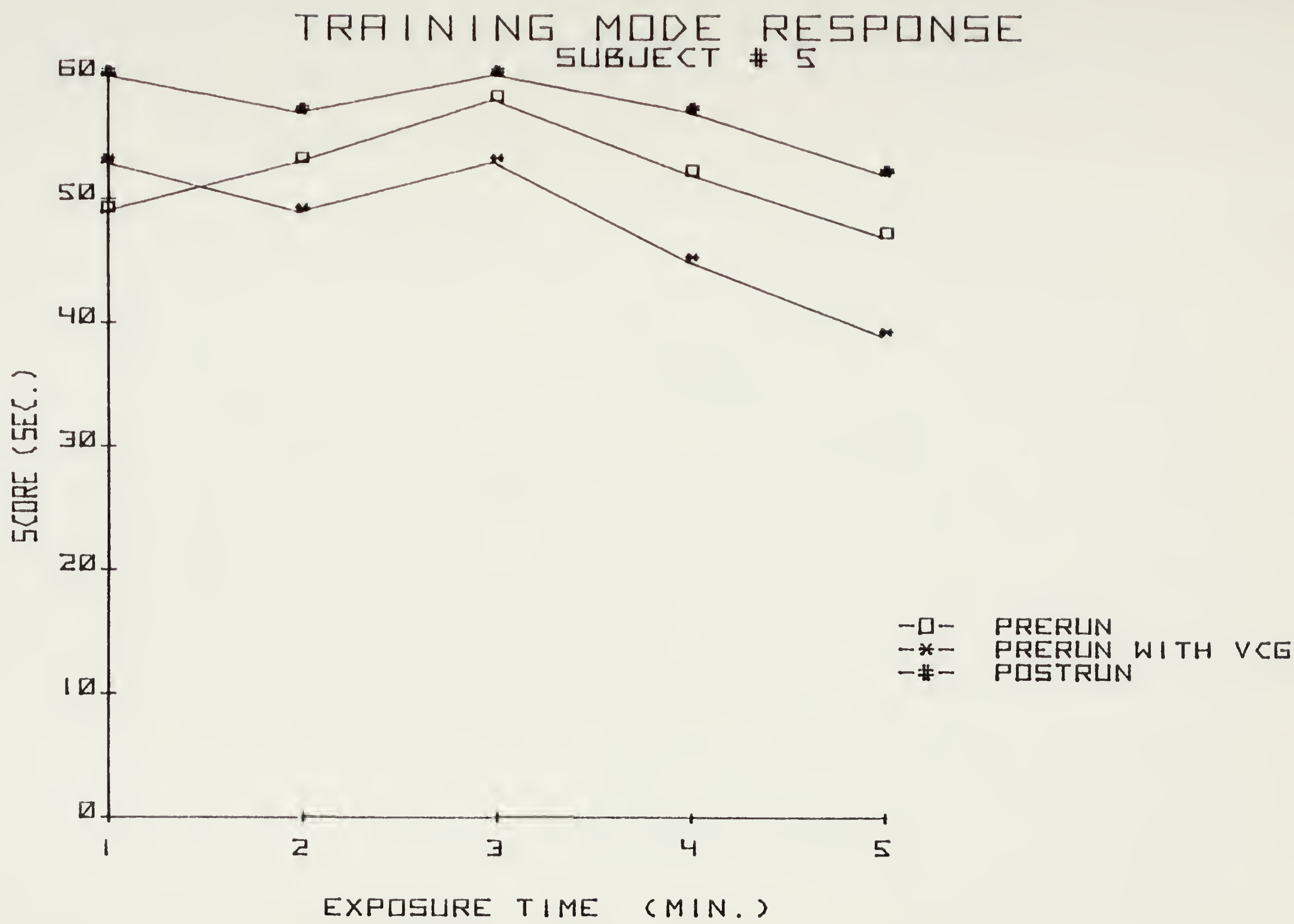

FIGURE 22. PHASE I, II, AND V SUBJECT #5 RAW SCORES

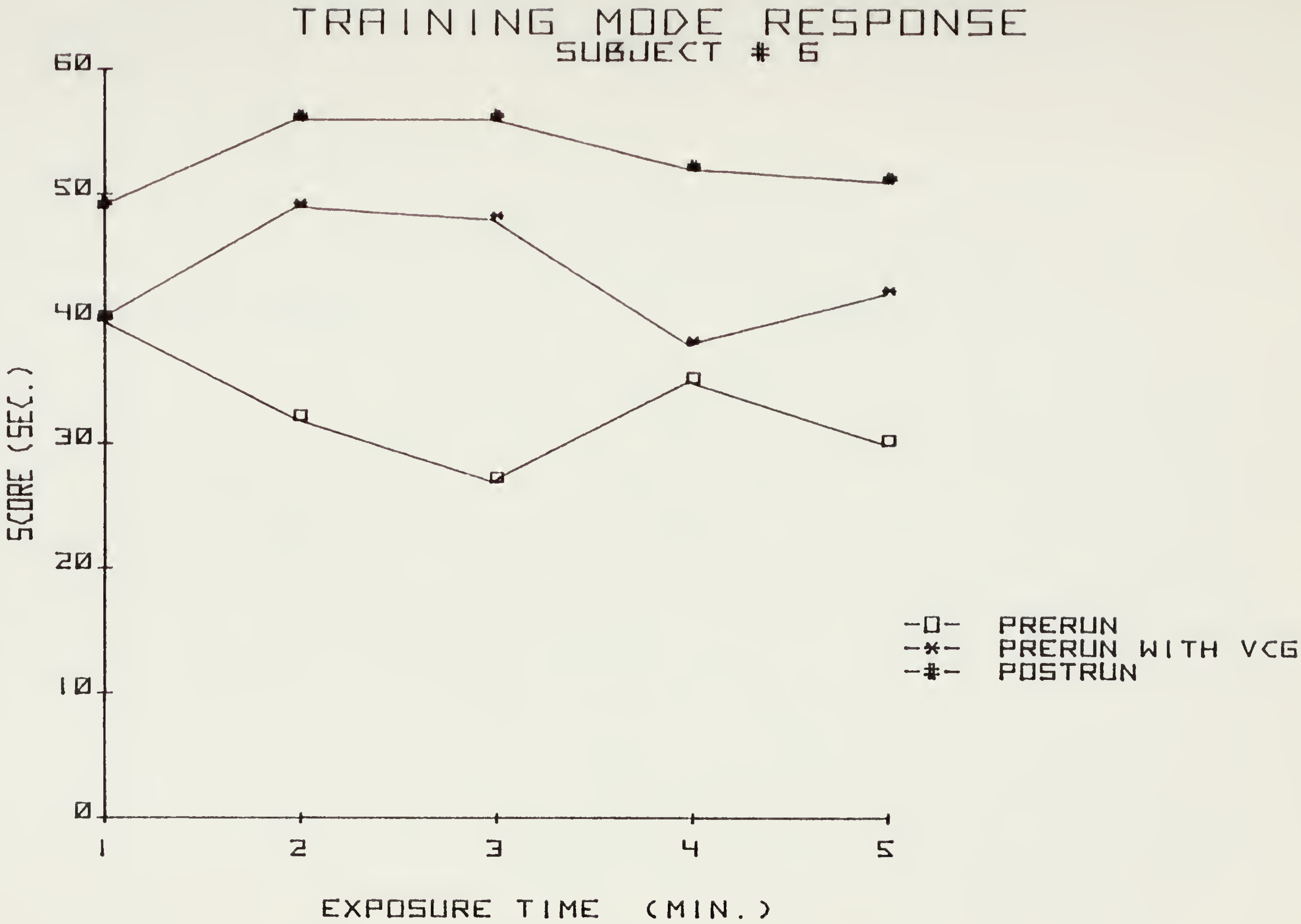

FIGURE 23. PHASE I, II, AND V SUBJECT #6 RAW SCORES

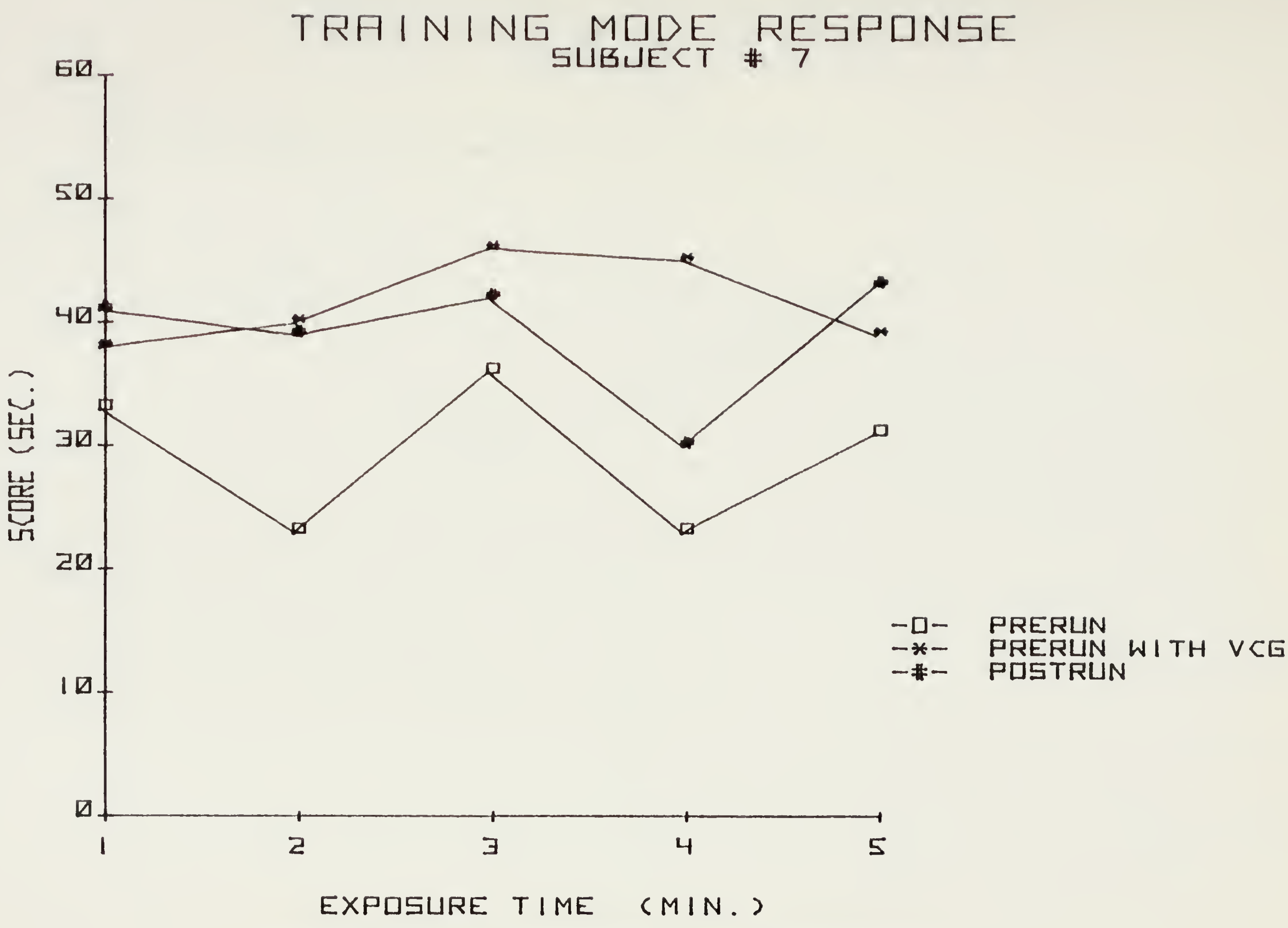

FIGURE 24. PHASE I, II, AND V SUBJECT #7 RAW SCORES

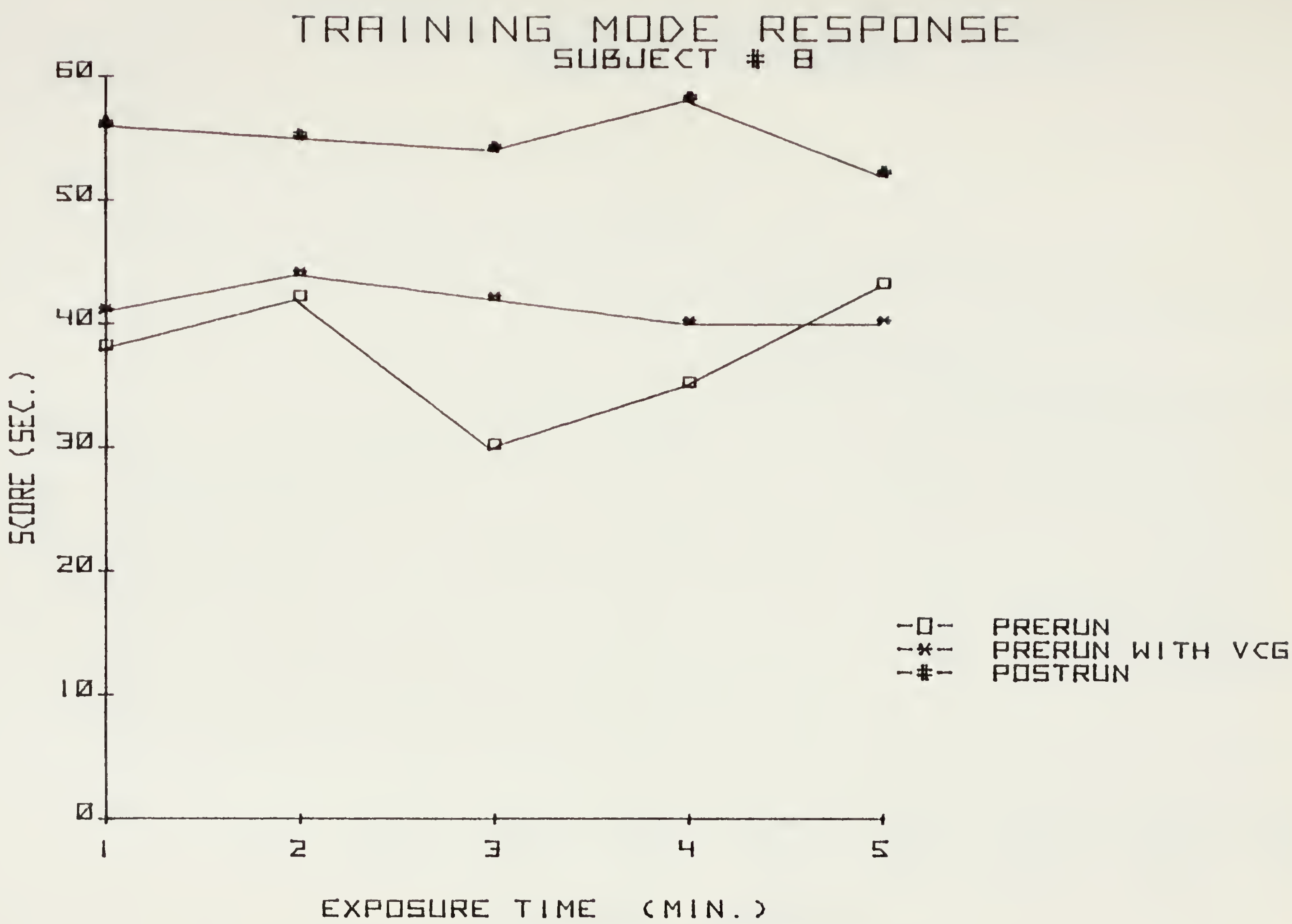

FIGURE 25. PHASE I, II, AND V SUBJECT #8 RAW SCORES

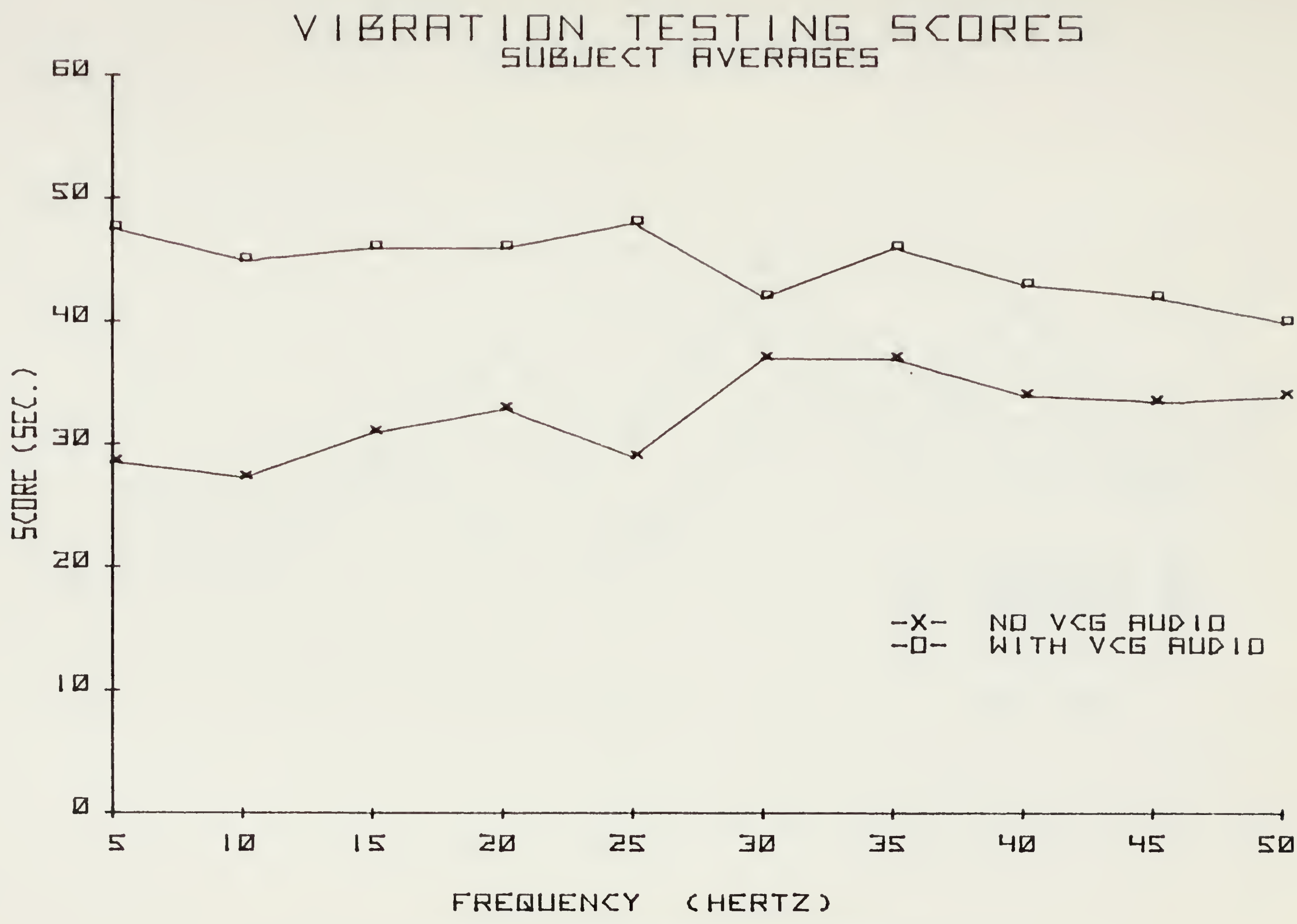

FIGURE 26. PHASE III AND IV AVERAGE SCORES

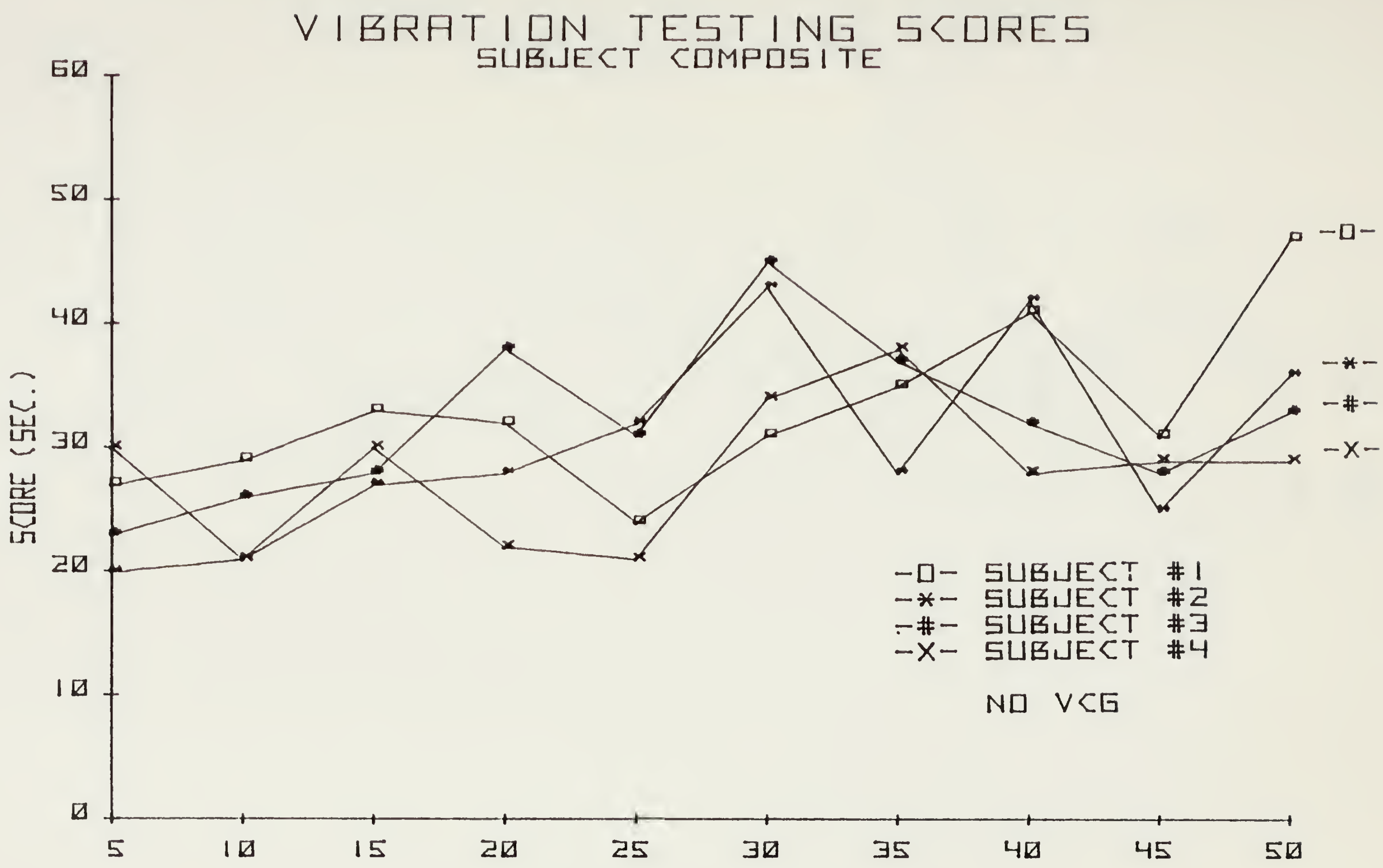

FIGURE 27. PHASE III RAW SCORES FOR SUBJECTS #1, #2, #3, #4

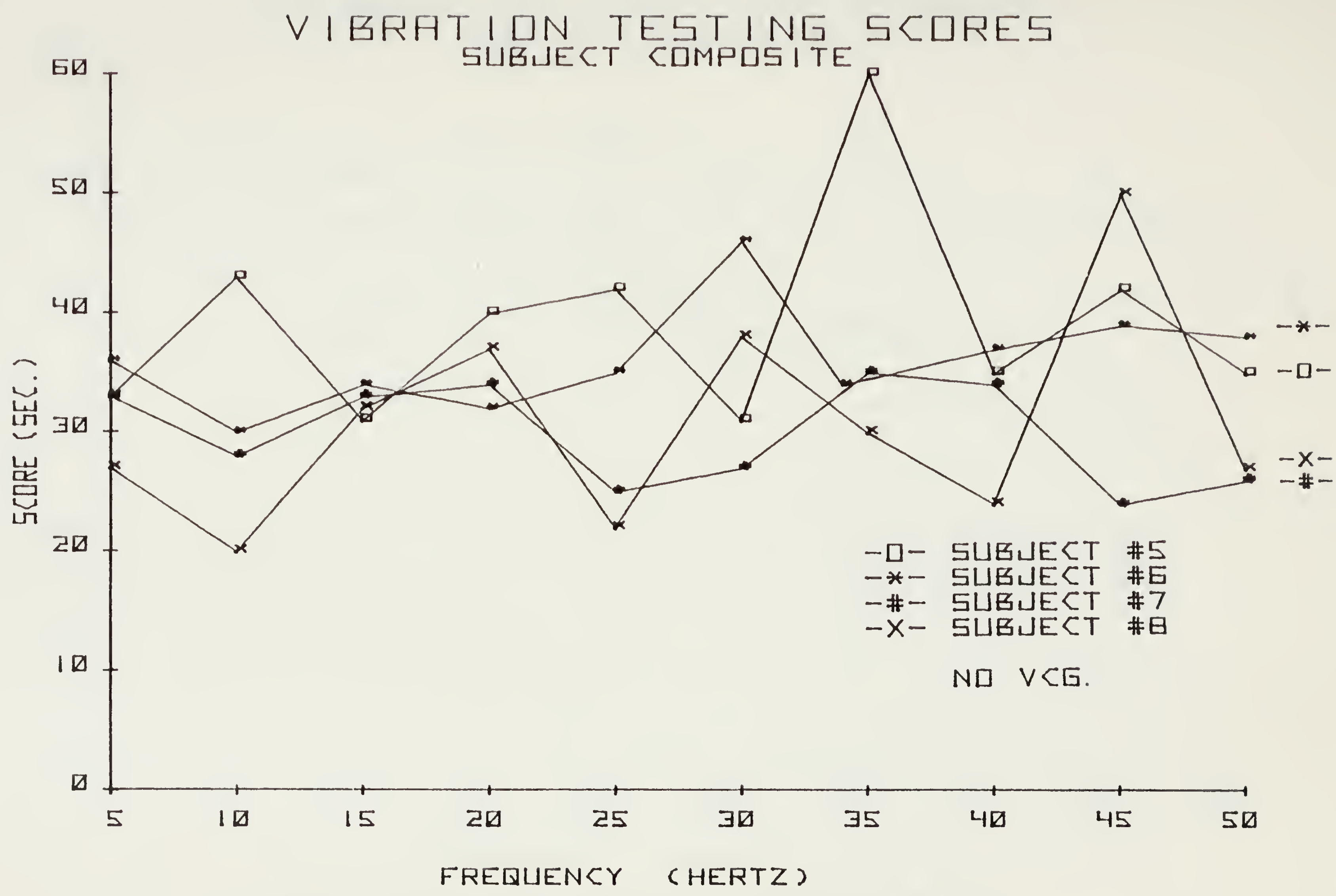

FIGURE 28. PHASE III RAW SCORES FOR SUBJECTS #5, #6, #7, #8

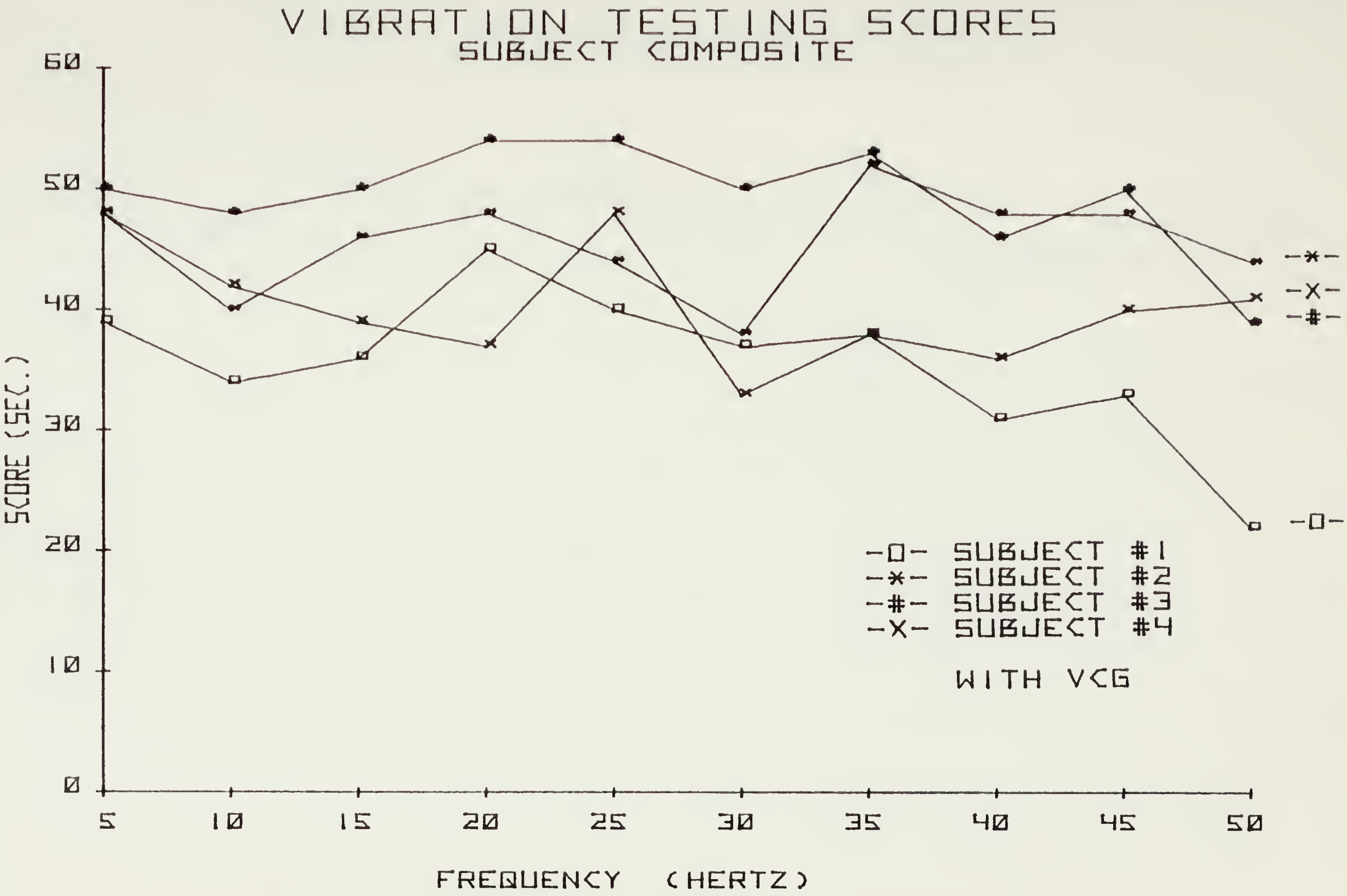

FIGURE 29. PHASE IV RAW SCORES FOR SUBJECTS #1, #2, #3, #4

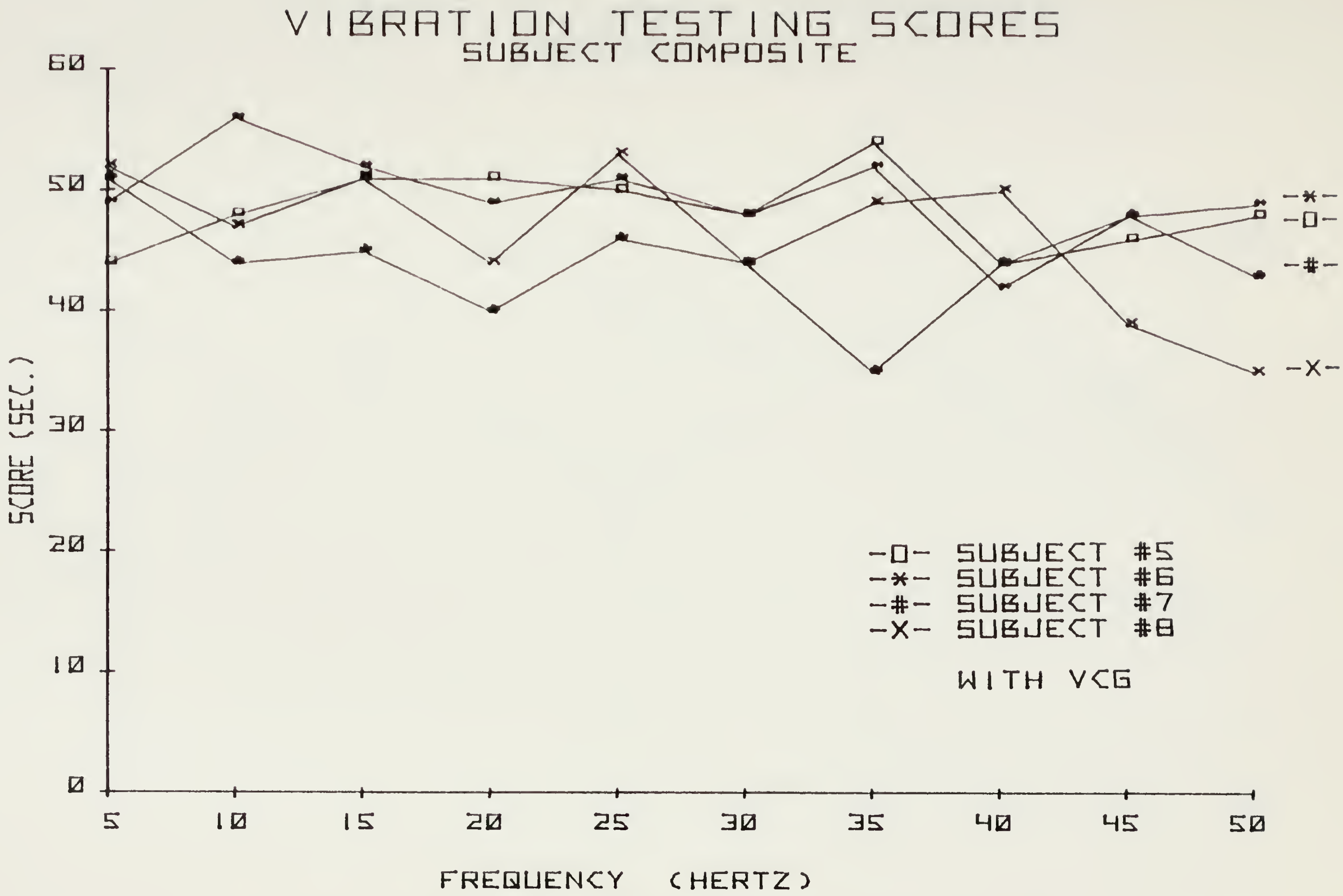

FIGURE 30. PHASE IV RAW SCORES FOR SUBJECTS #5, #6, #7, #8

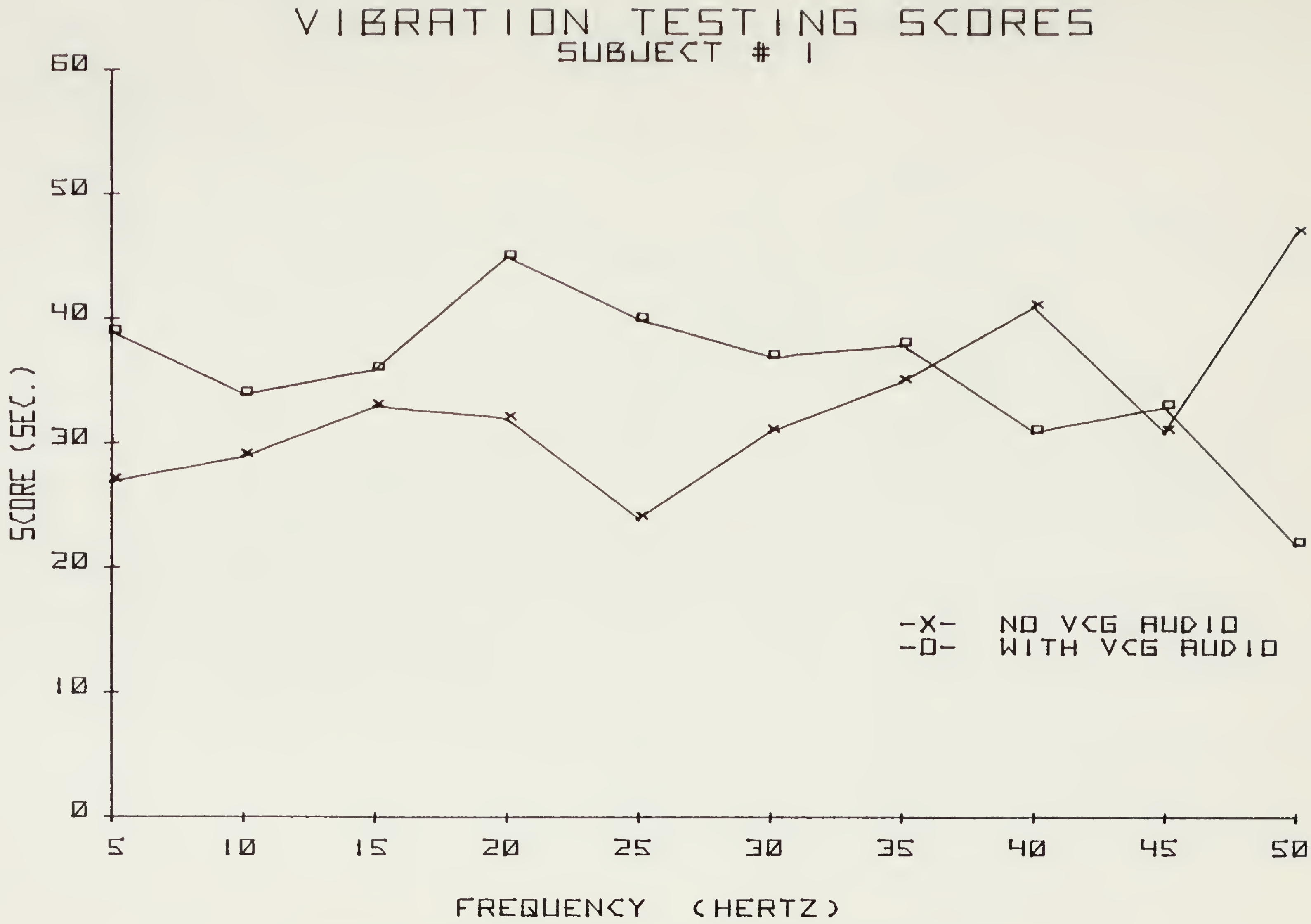

FIGURE 31. PHASE III AND IV SUBJECT #1 RAW SCORES

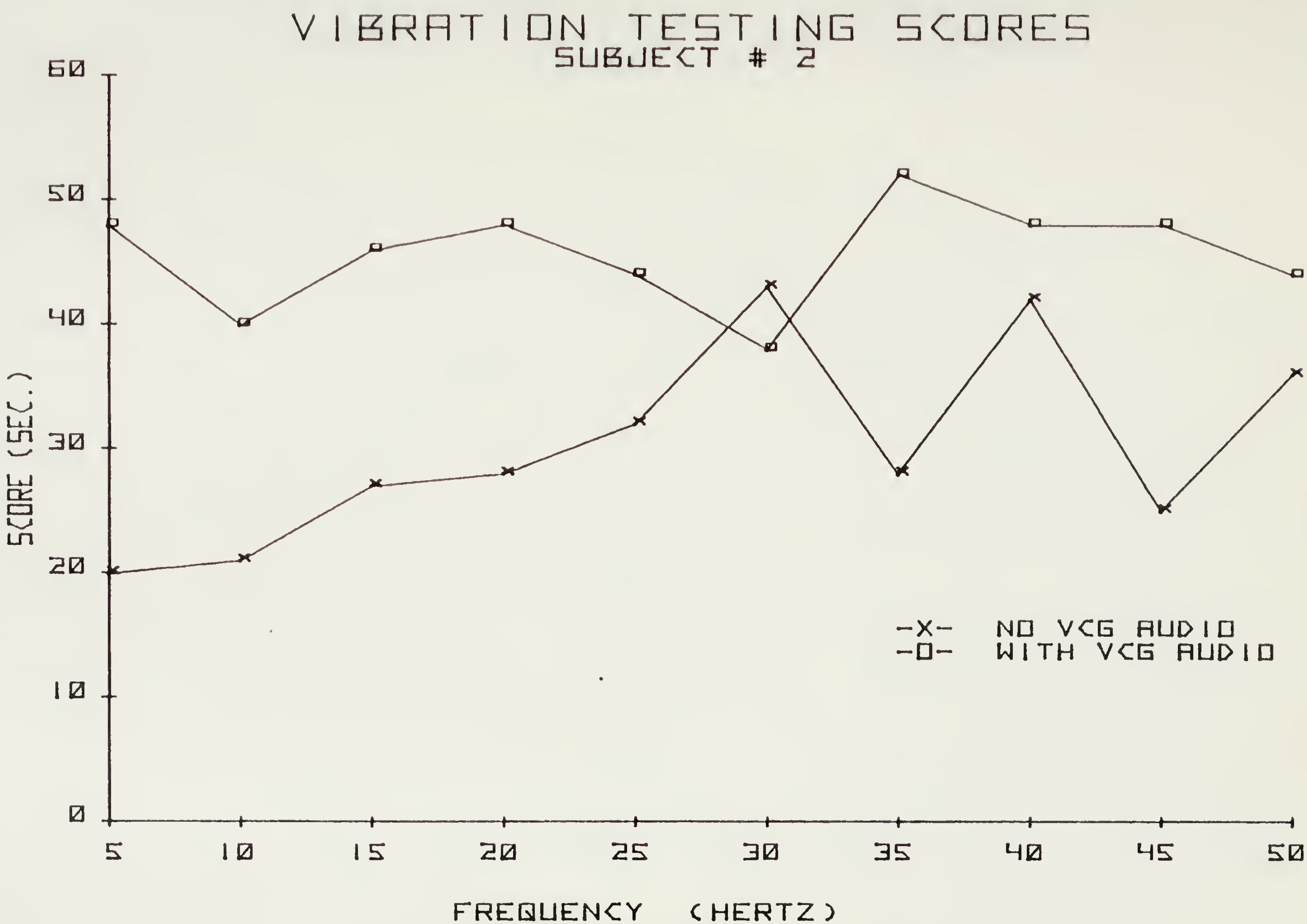

FIGURE 32. PHASE III AND IV SUBJECT #2 RAW SCORES

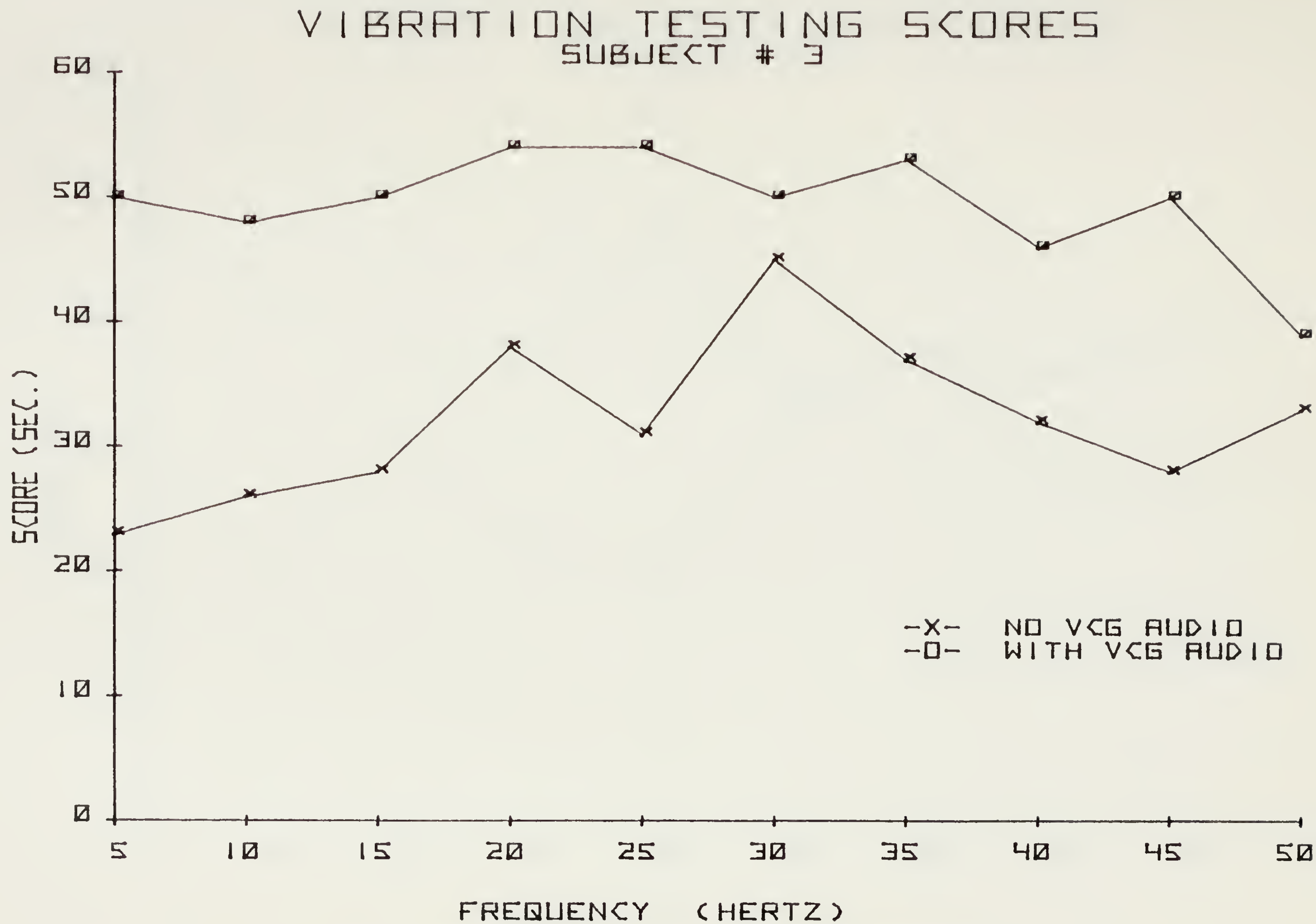

FIGURE 33. PHASE III AND IV SUBJECT #3 RAW SCORES

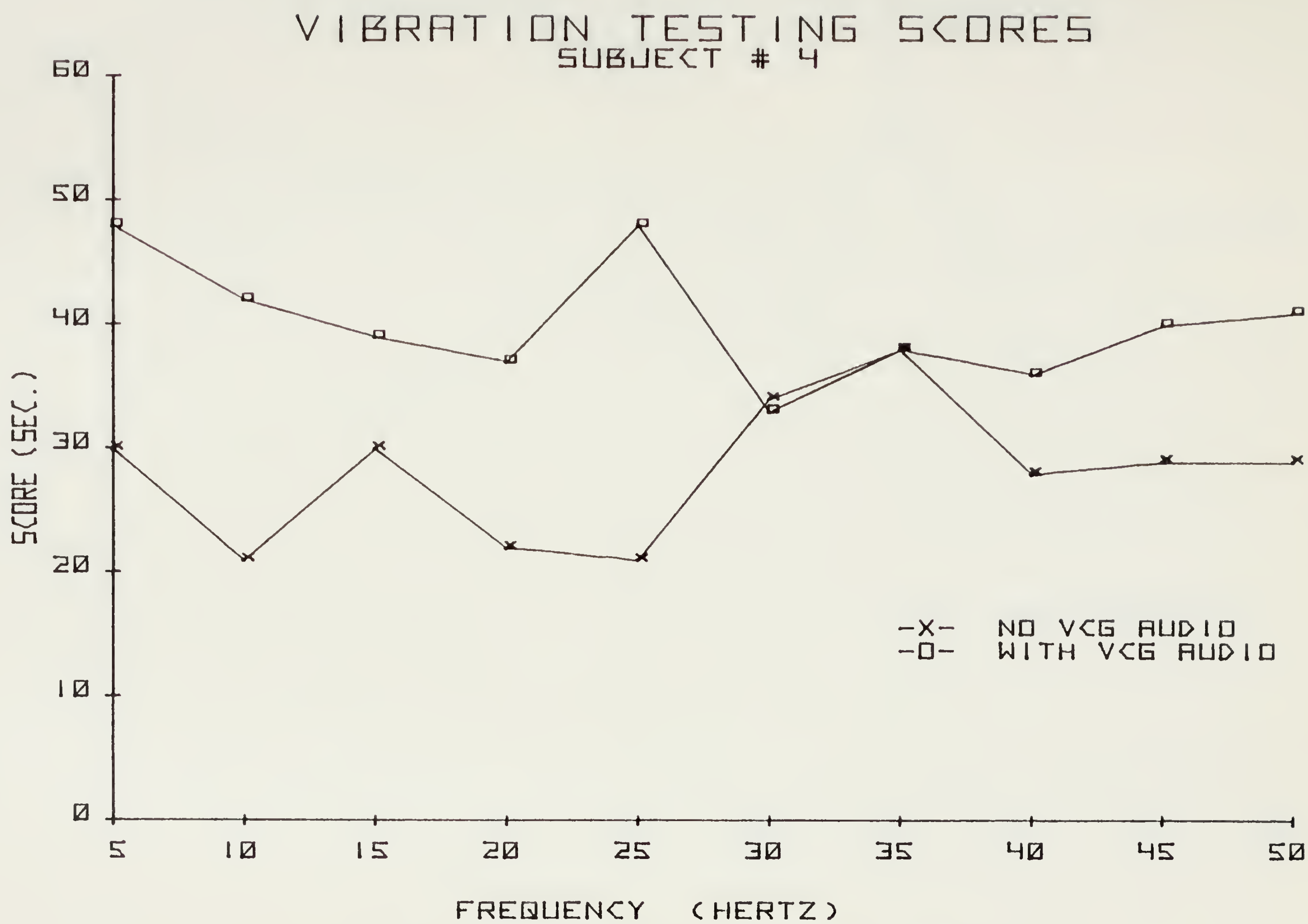

FIGURE 34. PHASE III AND IV SUBJECT #4 RAW SCORES

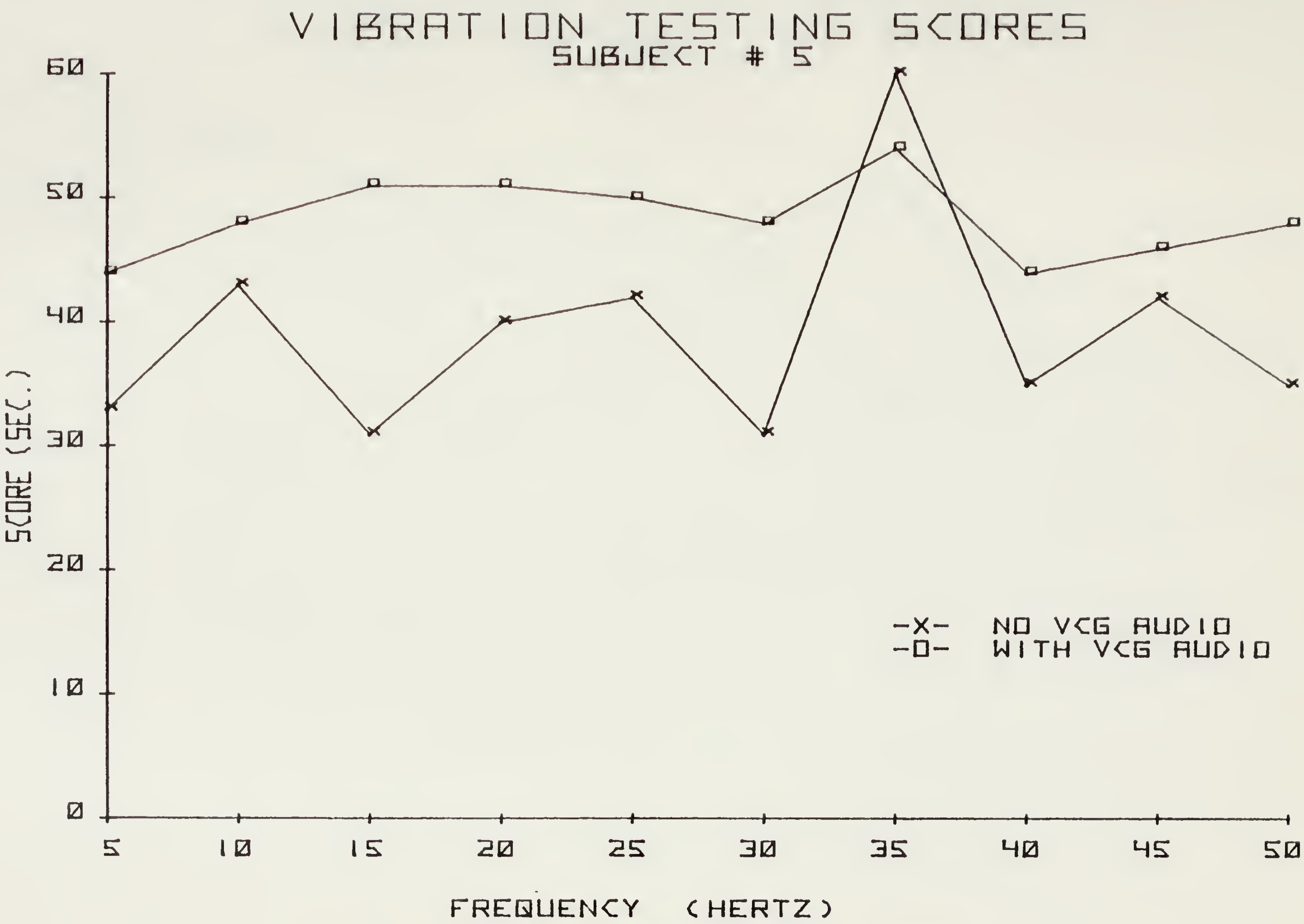

FIGURE 35. PHASE III AND IV SUBJECT #5 RAW SCORES

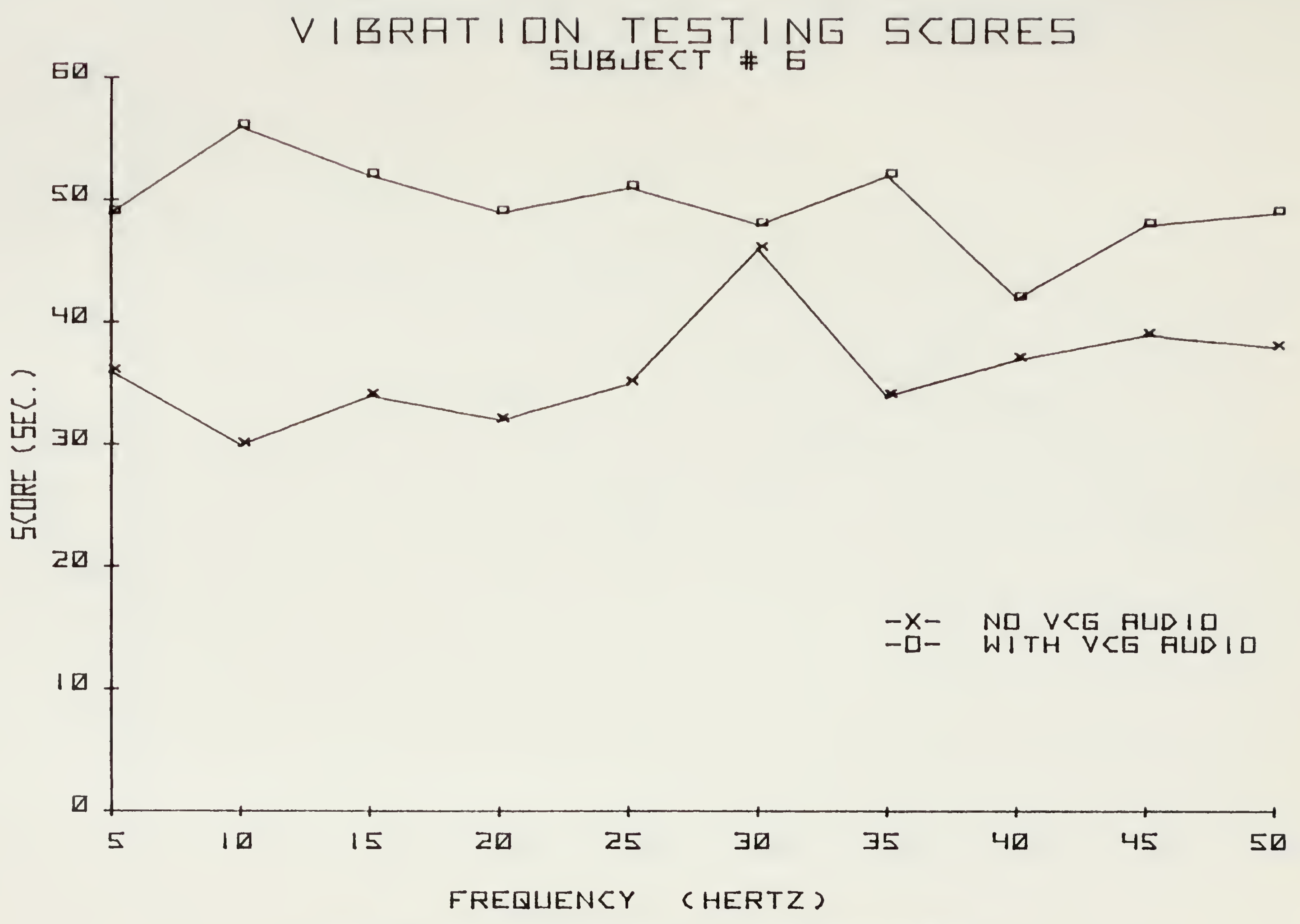

FIGURE 36. PHASE III AND IV SUBJECT #6 RAW SCORES

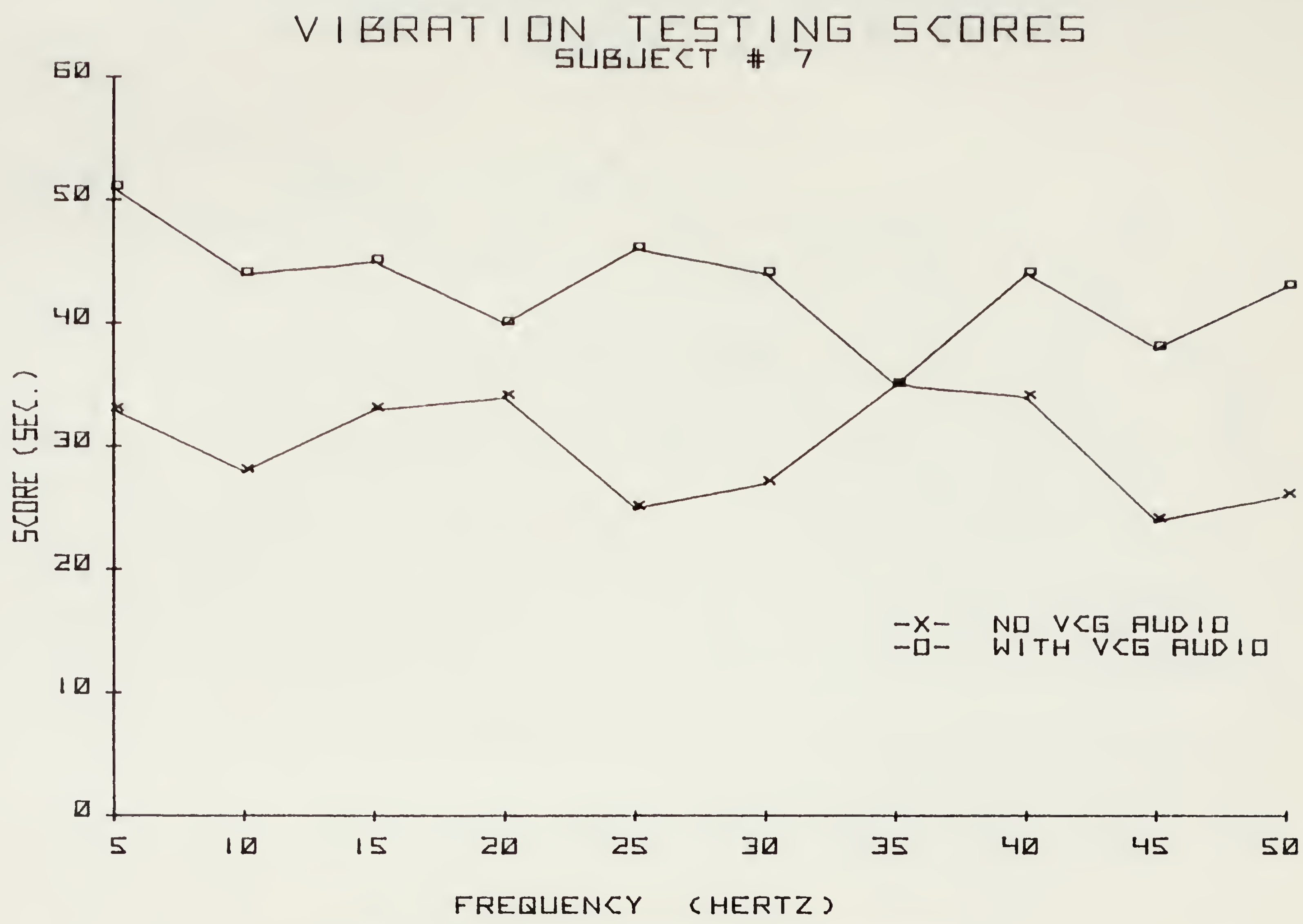

FIGURE 37. PHASE III AND IV SUBJECT #7 RAW SCORES

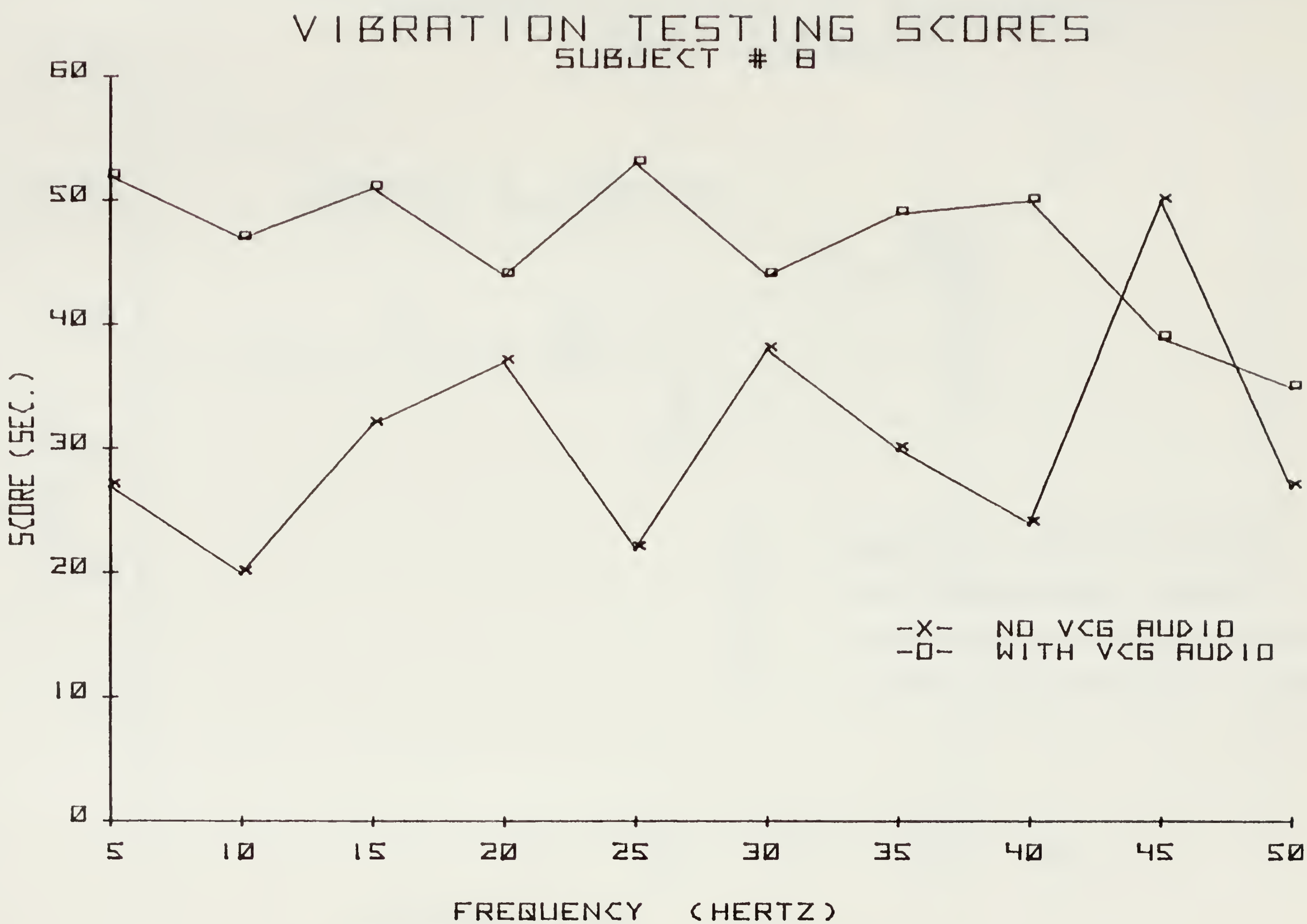

FIGURE 38. PHASE III AND IV SUBJECT #8 RAW SCORES

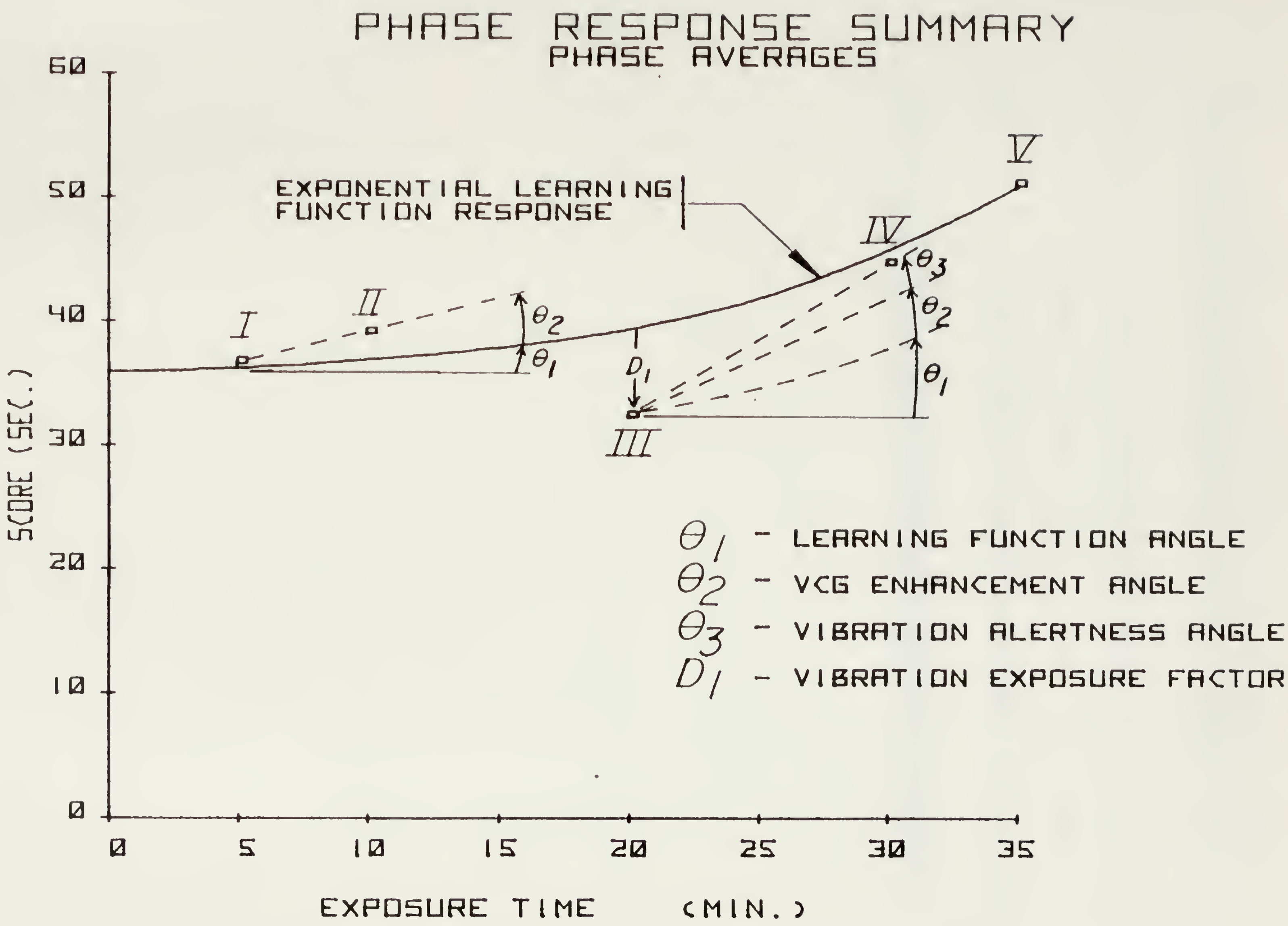

FIGURE 39. SUMMARY OF SUBJECT AVERAGE PHASE RESPONSE

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Thesis 198073
M4845 Mentas
c.1 A simulator evaluation of pilot response to low frequency aircraft vibration with audio feedback.